This manual is intended to serve as an aid to the understanding of the design, construction and performance of various types of otter boards currently in use in the trawl fishery of the world.

Its aim is to assist in the rational selection of the proper size and shape of otter board for specific fishing conditions and also to provide information useful for training fishermen in the handling and maintenance of the boards.

FAO FISHING MANUALS

OTTER BOARD DESIGN AND PERFORMANCE

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OTTER BOARD DESIGN AND PERFORMANCE

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
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CONTENTS

LIST OF FIGURES

INTRODUCTION

This manual is based on a manuscript which was prepared by J.J. Foster; G.M. Cameron; A. Corrigall; R.S.T. Ferro; and E.S. Strange and other members of the Marine Laboratory, Aberdeen, Scotland. Technical editing was done by the Fishing Gear and Methods Branch, FAO Department of Fisheries.

Its aim is to assist trawl fisheries in the rational selection of otter boards and to provide information useful in the training of fishermen. The manual is practice-oriented; theory is kept to an essential minimum and only basic mathematics are used. It sets out detailed information about the design, manufacture and operational aspects of otter boards most commonly used by commercial trawlers, with special attention paid to relative performances of the different types under various trawling conditions. Recommendations based on empirical data are given for the selection of appropriate types and sizes of otter boards.

The manual should not be considered as a comprehensive introduction to the physics and application of sheering devices; it is meant as a review of practical applications of the otter board in trawl fisheries.

No amount of improvement of only the otter board — which is just one part of an overall fishing system — will ensure fishing success, although it will contribute toward it. Indeed, vessel and trawl gear, with all its component parts, must be matched.

In the absence of a universally applicable basic formula for the calculations necessary in the selection of efficient trawl gear for various fishing conditions, recommendations on the matching of component parts of gear and ship will have to be based for some time to come on practical experience and engineering considerations. These unavoidable limitations, which imply the additional input of professional fishing skill and common sense, sshould be remembered when utilizing the information in this manual for specific cases.

The rules of hydrodynamics and mechanics discussed in this manual for otter boards also apply of course to kites and other sheering devices used in some trawl gear to provide dynamic vertical forces — for example, to secure appropriate opening height of the net mouth, to support false headlines or

to control the bottom contact or fishing depth of trawlnets. Since in commercial trawling flat rectangular boards are used almost exclusively for this purpose and since the share of such vertical sheering devices in the total drag of the trawl gear is negligible, they do not need to be specifically discussed here.

CHAPTER 1

BACKGROUND

1.1 Evolution of otter boards

In the days of sail fishing boats, towing speed was dependent upon the tides and the vagaries of the wind. This meant that often the net was scarcely moving and that hydrodynamically dependent means of holding the net mouth open could not be relied upon. Furthermore, at these slow speeds only short towing distances were possible. Consequently, the mouth of the trawlnet was kept open by a rigid and self-supporting frame structure, the resultant gear being known as a beam trawl (Figure 1). The length of the beam was restricted to the length which could be managed at the ship; this in turn set a limit on the maximum size of the net and hence on the area which could be covered during trawling operations.

The introduction of steam power to fishing vessels permitted faster and better controlled towing speed. This revolution in motive power opened the way to the introduction of hydrodynamically supported and controlled spreading devices to replace the rigid beam. Flat wooden plates, known even then as otter boards, were introduced to the gear fixed between the towing warps and wing ends of the net, with attachment points chosen to set them at an angle to the direction of towing so that the water force pushed them outwaed and thus held the trawlnet open in a horizontal direction. With the rigidity across the net removed, trawlers could not

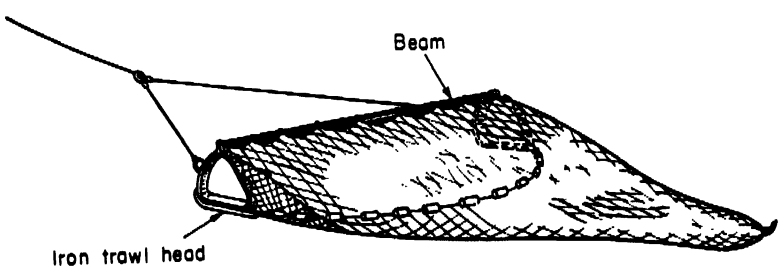


FIGURE 1. — Example of a beam trawl (modern version for shrimp trawling).

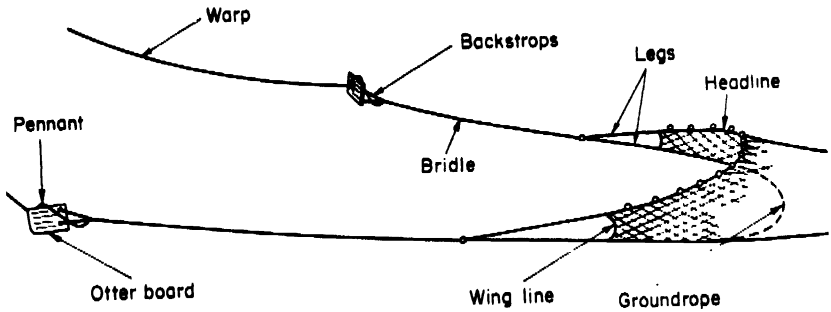


FIGURE 2. — Example of an otter trawl rigged with bridles.

only tow faster but were able to work wider opening nets and thus cover more ground. It should be mentioned that there are specific fishing conditions under which beam trawls are more suitable than otter trawls, and that beam trawls of modern design still exist or have even recently been introduced in highly mechanized fisheries (e.g., in Europe for shrimp and flatfish).

Whereas at first otter boards were simply connected directly to the wings of the net, today it is much more common to have bridles or sweep lines from a few to several hundred metres between otter board and net (Figure 2). It is not intended to discuss the herding effect of trawl gear in any detail, but fishermen early learned that long ropes or wires between net and otter board not only hold the net open horizontally but often sample an effectively increased volume of water or area of bottom per unit of fishing time (Figure 3).

Over the years there have been many improvements in the design of otter boards. New shapes and materials have been introduced to suit a much wider variety of fishing conditions and methods, including trawling in midwater.

The choice of otter-board shape will depend on a number of factors: whether it is to be used on or off the bottom; type of ground to be fished; size of trawler and its towing power; amount of diversity of intended trawling methods; and, last but not least, the cost. The size of the otter board must be related to its required reaction to the water-flow forces which push it outward in opposition to the in-pulling forces from the warps and the net. The points at which these forces act, that is, the position of the points of attachment of warps and bridles, must be chosen so that the balance of forces holds the otter board in the position which allows it to operate at the best average efficiency. Material and thickness must be chosen to suit the imposed stresses and strains, the required overall weight and the distribution of weight for good stability.

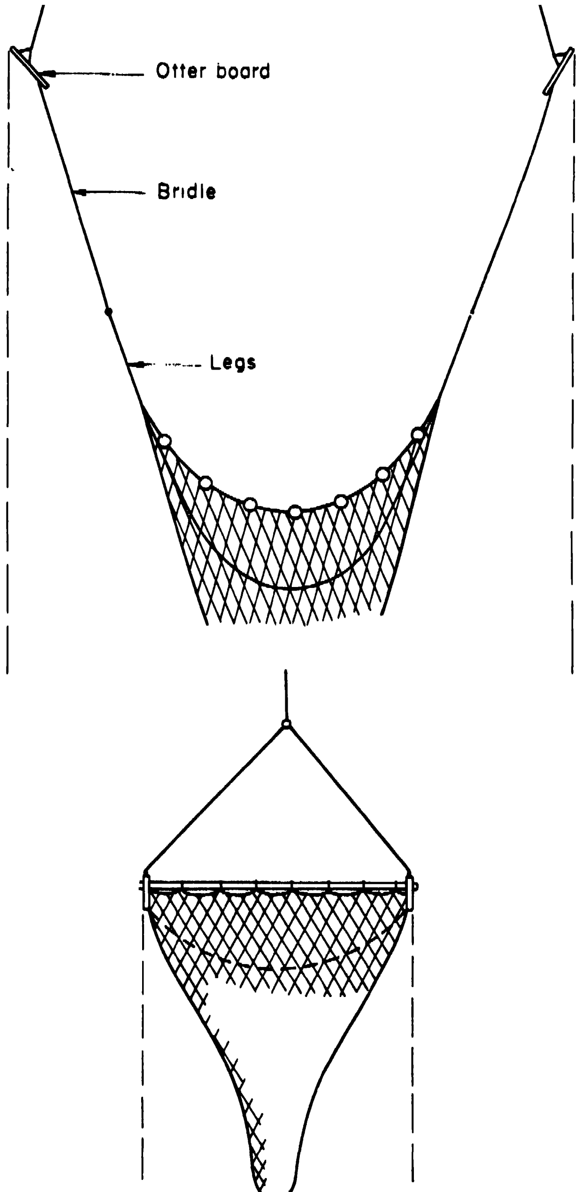


FIGURE 3. — Comparison of areas covered by otter trawling with bridles and by beam trawling with nets of the same opening width.

1.2 General principles of otter board dynamics

An otter board has no power of its own to move and to spread the connecting wires to which it is attached. Its ability to do so is derived from the interaction of external forces. How well it spreads the connecting wires (i.e., warps and bridles) and, hence, the net, depends on its shape and size and how well the forces are harnessed to it. The main forces to be considered are: towing power of the trawler, drag (towing resistance) of the net, hydrodynamic forces of water flow, gravity and bottom friction.

1.2.1 Towing force

The towing force or pull of the trawler is transmitted to the otter boards through the warps. In the towing condition, the warps leave the trawl gallows or slip hook at an angle with components of declination and divergence, the latter due to the deflecting action of the otter boards. Throughout their length, the direction of the run of the warps is modified by gravity and water forces against them imparting a certain curvature. The amount of curvature varies slightly with changes in warp length and warp vibration; the latter effectively increases the area of the warp projected to the direction of tow by an amount depending on the frequency and amplitude of vibration. All these factors influence the direction of the warp at the otter board and hence modify the towing force imparted by the ship, so that, in addition to the towing force, the tension in the warp has components of lift and in-pull forces. The magnitude and direction of these force components must be taken into account when selecting the size and weight of the boards and choosing the position at which to connect them to the warps.

1.2.2 Drag of the net

The drag of the net comprises the hydrodynamic forces acting on the netting, the net appendages such as headline lifters (floats or kites), the groundrope, the hauling ropes and the bottom friction where there is ground contact. The magnitude of these forces depends on the amount of netting in the net; sizes of netting twine and meshes; number, shape and size of all the appendages; overall shape of the net; and towing speed.

The total drag of the net is transmitted through the bridles or sweep lines which connect the net to the otter boards. With the otter boards deflected, these ropes or wires adopt an angle of attack to the direction of tow (Figure 4). As with the warps, the connecting wires are influenced by gravity, water forces and bottom friction when there is ground con-

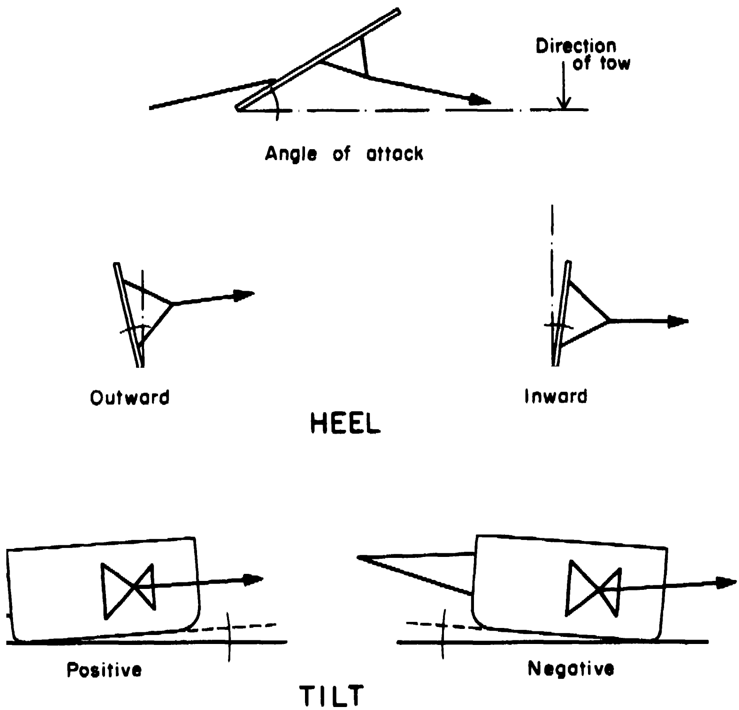


FIGURE 4. — Definition of otter board attitudes.

tact, giving them curvature and thus influencing their orientation at the otter boards; consequently the tension in the bridles also has components of net drag, in-pull and slight down-pull at the otter board end.

1.2.3 HYDRODYNAMIC FORCES

In the towing condition, the water forces act on the otter boards in opposition to the in-pull components of the tensions in the warps and bridles. The magnitude of these forces depends on the density of seawater, the towing speed, the size and shape of the otter boards and their angle of attack.

For practical purposes, the density of seawater is constant, independent of depth, temperature or salinity. The size of the otter boards determines the area of the water that meets them, and changes in towing speed vary the

volume of water which meets the otter boards per unit of time. Their shape, appendages, size, angle of attack and towing speed influence the water-flow patterns round the otter boards. These flow patterns, such as back eddies and vortices which slightly counter the pressure on the boards' front faces and suction-producing regions of low pressure, influence the overall spreading efficiency and can be exceedingly complex.

The resultant force of all the combined water forces acting on an otter board is at right angles to its face through its centre of pressure. It follows that the relationship of spread, drag and vertical components in the resultant hydrodynamic force depends on the orientation of the otter board of which the angle of attack is the principal angular component. In some cases, the angles of heel and tilt must also be considered (Figure 4).

1.2.4 Gravity

The force of gravity acts on the mass of all the components of otter boards, giving them weight. Of course, displacement of water provides some upthrust and reduces the weight. The result of all gravity forces is downward through the centre of gravity of the otter board. The position of the centre of gravity, and hence its contribution to the degree of stability of an otter board, depends on the mass and distribution of the different structural components (see 4.9). It should be mentioned that in certain cases specific buoyancy is provided to support an upright position of the otter board (e.g., diverting depressor, attachment of floats along the upper edge of light flat rectangular otter boards, full profiles of Japanese high aspect ratio cambered boards). In such cases the uprighting movement, which depends on the vertical distance between the centre of gravity and the centre of buoyancy, has also to be considered.

1.2.5 Bottom friction

The strength of the force of friction depends on the nature of the bottom and the sole of the otter board, which are in contact, and on the force pressing them together. In the case of bottom-trawling otter boards, this force is the resultant of their weight and the vertical component of the water forces which may be reduced by an upward directed component of the warp tension. The magnitude of the force of friction is not dependent upon velocity — that is, the force required to overcome friction is the same, however fast the otter boards are moving. Whereas bottom friction will slightly retard the time it takes for the otter boards to settle to a new position after a change in towing speed, at a steady speed it makes no contribution to the total spreading force, but adds to the total drag of the gear.

The influence of the bottom on the performance of demersal otter boards is not restricted to pure friction. Apart from mechanical stress on hard and rough grounds, ploughing in softer grounds such as sand will add to the towing resistance, but will also increase spreading force. In soft mud, otter boards can be pulled in to such an extent that the trawler becomes anchored or the warps part. In general, the bottom provides the most variable and least controllable external influences on demersal otter boards. It is therefore in certain respects advantageous to reduce bottom contact. Some types of otter boards are more suitable for this than others (see Chapters 4 and 5).

1.2.6 Interaction of forces

The horizontal forces described above are shown in Figure 5: **A** shows these forces in relation to the whole trawl gear and **B** with their drag and in-pull or out-pull components. In order that the otter board may move outward, the total of out-pull force components 3a and 4a must be greater than the total of in-pull force components 1a and 2a. Otter boards reach their maximum spread when the total out-pull matches the total in-pull.

In Figure 6, the forces acting on a bottom-running otter board are shown viewed from its end elevation. With the otter board heeled outward, as shown, the resultant of hydrodynamic forces has a downward direction with a down-pull component which presses the otter board harder onto the ground. If it were heeled inward, the resultant would have upward direction with an up-pull component which would tend to lift the otter board away from the bottom. The resultant of weight and water forces pressing the otter board down onto the seabed is counteracted by the seabed itself and the eventual upward component of the warp tension. Any change in the magnitude of this vertical force will naturally change the effective thrust of the board against the bottom and alter the amount of bottom friction. In midwater trawling, there is no ground contact and therefore no ground to support the boards' weight; this must be balanced by other forces. The weight factor is therefore more critical than for bottom-running otter boards and variable ballast plates may be used to ensure proper performance.

If the otter board is heeled inward or outward (Figures 4 and 6), some hydrodynamic spread is sacrificed by an amount depending on the degree of heel. However, to meet certain fishing conditions, the advantages gained from adjusting the rigging of the otter boards to heel either inward or outward (and thus either to reduce or increase their weight factor respectively) usually outweighs the disadvantage of some reduction of spread. This is particularly so for otter boards used exclusively in midwater, where variations in otter board depth are brought about by varying speed and warp

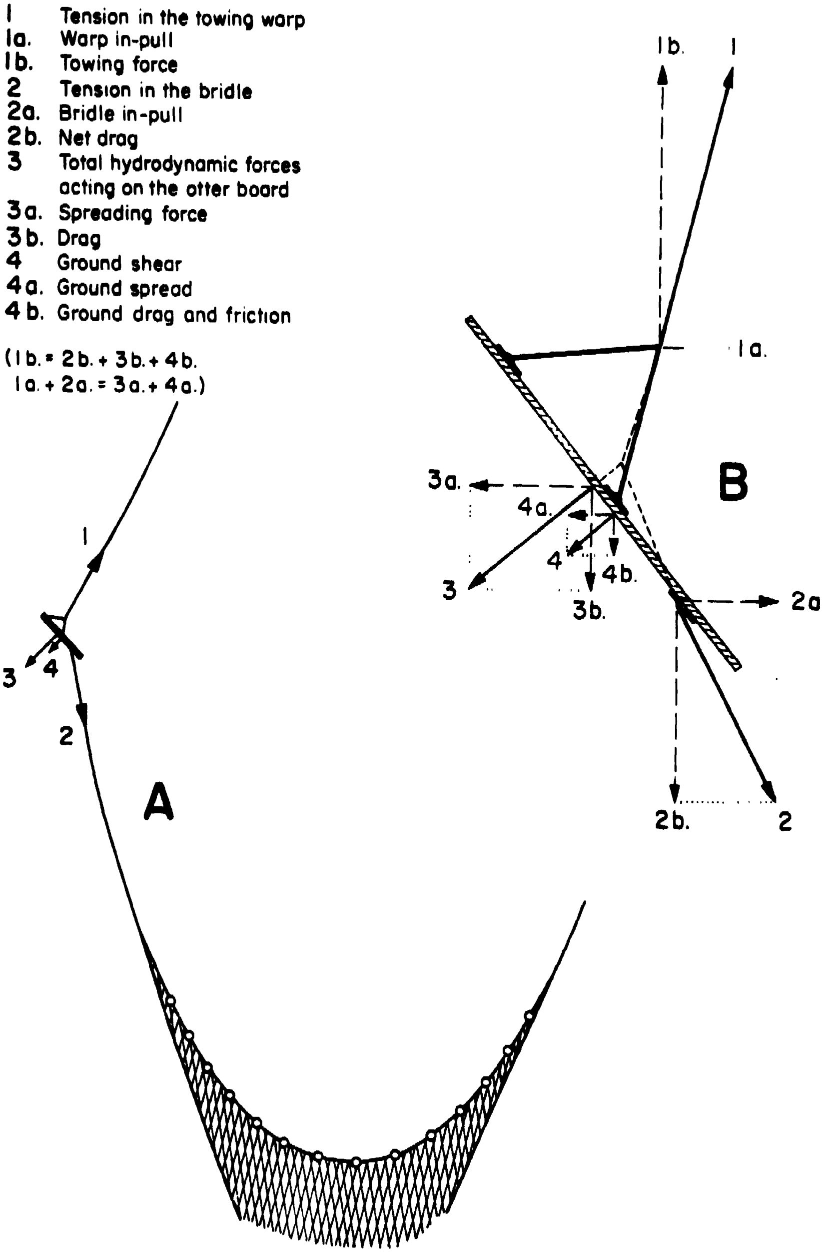
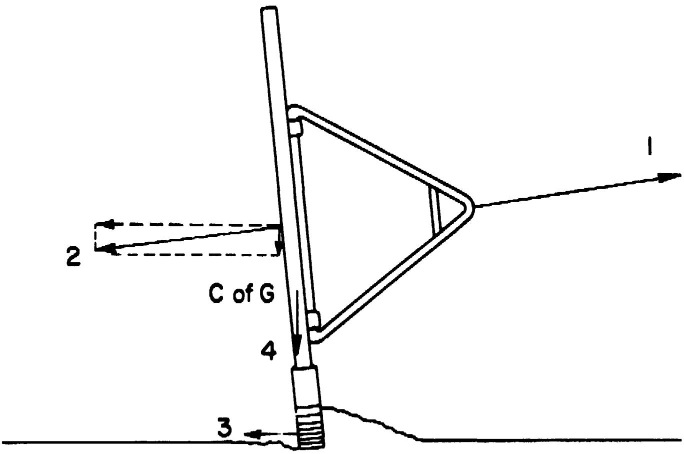


Figure 5. — The main horizontal forces acting on an otter board.



1. Tension in the towing warp
2. Total hydrodynamic forces
3. Ground reaction
4. Weight acting through center of gravity

FIGURE 6. — The main forces acting on an otter board viewed from the leading end.

out during towing. This puts heavy demands on the towing power of the trawler and the trawl winches. For this reason, midwater otter boards are often designed with a speed-controlled amount of angle of inward heel to provide additional hydrodynamic lift for the otter board and to support and accelerate the lifting of the net.

Apart from heel, the tilt (Figure 4) of an otter board may also significantly influence its performance, particularly on the bottom. Positive tilt favours light bottom contact; negative tilt favours digging in. Zero tilt gives the most even bottom contact along the length of the board and therefore maximum additional sheer through ploughing, but also maximum additional drag. Usually a slightly positive tilt is desirable as it facilitates passing over obstacles. In soft mud, excessive positive tilt may reduce the angle of attack to such a degree that adjustments are needed to maintain appropriate sheer. These may consist in a reduction of the positive tilt or in the shifting forward of the points of attachment of the backstrops.

Although the importance of such operational aspects of otter board rig are fully recognized, they are considered to be outside the scope of this manual and therefore will not be discussed in any detail.

CHAPTER 2

OTTER BOARD INVESTIGATION AND THEORY

Without complex scientific equipment such as underwater television cameras or underwater vehicles it is not possible to observe trawl gear in fishing operation on the seabed. However, it is very useful for both the gear designer and fisherman to be able to compare the performance of different types and rigs of otter boards so that the most suitable board can be chosen for a particular job.

Basically there are two ways of judging engineering performance:

1. By direct observation of an otter board, not under normal fishing conditions but in simulated or artificial surroundings either in the laboratory using a water tank or in shallow inshore or inland waters which permit the use of divers.

2. By determination of the forces produced by the otter board — the information being gained either by direct measurement or by calculation using mathematical equations to represent the interactions of these forces.

The manufacture of full scale otter boards is expensive and the cost of a series of trials on a variety of new designs of otter boards could prove to be prohibitively high if an example of each type were built, only to have some or all of them discarded after the tests.

A solution to this problem is to assume that a smaller scale model (e.g., quarter size or one-sixth size) will behave in action in exactly the same way as its full-scale counterpart (see 2.2.2). Within certain limitations, observation of model boards gives a good indication of the behaviour of their full-scale equivalents in fishing.

2.1 Direct observation

Trials have been carried out successfully (Akre, 1965; Dickson, 1959; I.F., 1967; Schärfe, 1966) with complete gear of between 1:2 and 1:6 scale towed behind relatively low-powered boats in water depths of less than 20 m. Divers are able to work comfortably at these depths and, while swimming or being towed along in close proximity to the gear, can note changes

in configuration of the otter boards and net when such parameters as speed and warp length are altered. Further approximate comparisons can also be made between alternative rigs or different otter boards by the use of instruments to measure the spread or height of the net, the loads in the wires and the spread of the otter boards. Instead of employing relatively complicated instrumentation, it is possible for divers to use lengths of twine to give an indication of spread or graduated poles to give an indication of headline height.

The location of this type of test may usually be chosen so that the gear is towed over an unobstructed, level area of seabed (to ensure gear stability and divers' safety), although this will not, of course, then simulate full-scale performance over rough ground.

A disadvantage of employing divers is that the experiment is restricted to low speeds, since a diver's face mask may be torn away at speeds exceeding about two knots. For this reason, underwater vehicles have been used. An early version was that used in the tests by Akre (1965); it was a towed "wet" type which divers held on to behind a protective visor. Another design is the towed "dry" vehicle in which the personnel are totally enclosed (e.g., the Russian Atlant I and the new Scottish Towed Underwater Vehicle). Another possibility is a self-propelled vehicle, which is, of course, much more complex. Observation from all these vehicles requires relatively clear water, but considerable information may be obtained on gear performance.

Smaller scale models can conveniently be observed in a water channel or flume. These are usually of rectangular cross section through which the flow of water is controlled (Narasako and Kanamori, 1959). Thus, instead of the trawl moving through the water, the water flows past the stationary trawl model. A complete scaled-down trawl model is secured by means of wires attached to the otter boards at the warp brackets. Often the walls of the observation chamber of the channel are made from transparent material so that the gear may be viewed from the sides as well as from above.

Such a facility is available in Boulogne-sur-Mer, where 1:10 to 1:20 scale models of complete trawl gear can be observed or tested (Nédélec and Portier, 1968). However, as a general rule, the larger the model, the more representative it will be and it is thought that a 1:15 scale is approaching the maximum reduction in size which should be recommended for otter boards. At Boulogne-sur-Mer, there is the added facility of being able to simulate ground contact. A section of the channel floor has a suitably prepared surface and can be made to move in the appropriate direction relative to the otter boards and net to create the effect of the gear travelling over the seabed, while reducing water turbulence along the bottom.

This type of model test (observation) usually enables only a limited quantitative assessment of gear behaviour to be obtained because of difficulties in ensuring similarity between models and full scale, but is a useful way of giving observers a "feel" for the reaction of a trawl to different towing speeds and the changes in configuration brought about by alterations to the rig.

There are other methods of testing model trawl gear employing larger models (of not less than 1:8 linear scale):

— a large version of the channel described above in which the water flows past the model;

— a wind tunnel in which air and not water flows past the model. Higher speeds have to be employed in this case, to ensure similarity of performance of the model in air and the full-scale version in water (Stengel, 1963);

— a towing tank in which the model is towed by a movable carriage mounted above a long tank of water up to several hundred metres in length (Schärfe, 1966; Walderhaug and Akre, 1963).

In these three types of test, sufficient accuracy may be obtained for measurements to be taken and comparisons made between the performances of different designs of nets and otter boards.

2.2 Measurements and calculation

The efficiency of an otter board may be conveniently expressed by means of two forces: (*a*) the outward-spreading force which is at right angles to the direction of motion and (*b*) the drag force, or resistance to motion, which acts backward directly against the pull of the ship. Clearly, an efficient board will have a large spreading force and a low drag. In bottom trawling, these forces are made up of the sum of both the hydrodynamic and ground contact forces in the two directions (Figure 5). If these forces were known for each type of otter board, it would be a simple matter to compare their magnitudes and decide which gave the required spreading force for the least drag.

It is not possible either to measure directly these two forces acting on an otter board being towed under normal fishing conditions, or to calculate them by considering the extremely complex water flow round the board.

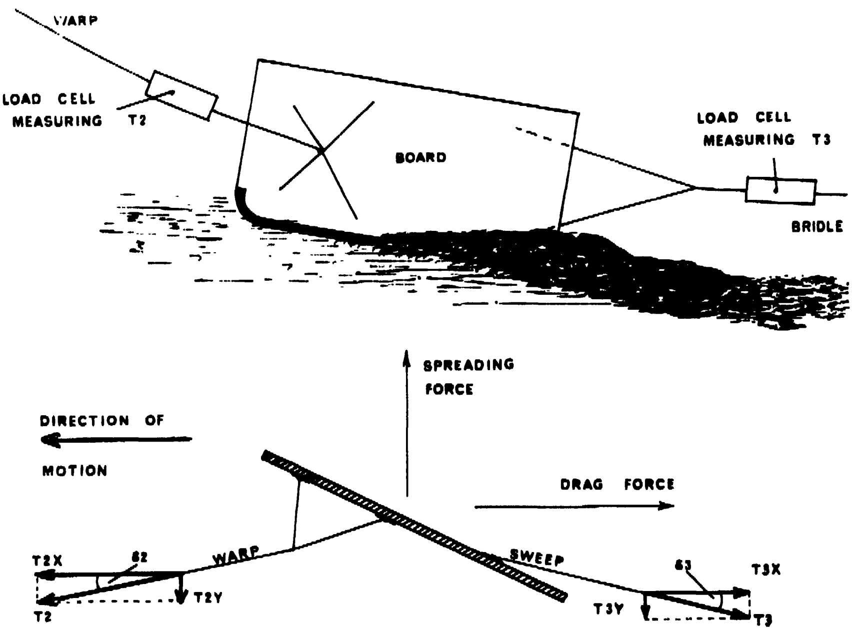
Values for these forces — spread and drag — can be obtained, however, by the two methods described briefly below. Comprehensive examples are also given for various types of otter board.

Since the use of trials data in design is thought to be important, particularly in reducing the cost of developing improved fishing gear and increasing efficiency, the following sections discuss the derivation of the methods in some detail. It has been necessary to employ a few mathematical formulae

in the text which, although difficult to explain in simple terms (and this has not been attempted), are not at all complicated in concept.

2.2.1 Full-scale trials

Although it is not possible to measure directly the drag and spreading forces of an otter board when it is being towed under normal fishing con-



SPREADING FORCE = T2Y + T3Y

DRAG FORCE = T2X - T3X

T2X — T2 cos δ2

T2Y — T2 sin δ2

T3X — T3 cos δ3

T3Y — T3 sin δ3

Figure 7. — Locations of load cells for measuring forces in warps and bridles (*above*) and derivation of the spread and drag forces from respective tension measurements.

ditions, these forces may be calculated using measurements obtained from instruments capable of withstanding high water pressure (see Nicholls, 1964; MacLennan, 1969: Carrothers, 1968) which measure the loads in the warp immediately in front of the board and in the bridle immediately aft of the backstrops. Figure 7 shows the position of these load cells, as they are called, for a conventional flat rectangular otter board. The load cells are analogue instruments recording the tension as a line marked on heat-sensitive or other type of paper with graduations.

Figure 7 also shows a view of the otter board from above with the warp and bridle wire loads, T2 and T3, marked with double arrows. These tensions are equivalent to (i.e., have exactly the same effect as) two components as shown, in the drag and spreading force directions (that is, in the X and Y directions). Thus, if the angles of the warp and bridle to the direction of motion and the wire loads are all known, it is possible to calculate T2X, T3X, T2Y and T3Y, since

$$\begin{aligned} T2X &= T2 \cos \delta 2 \\ T2Y &= T2 \sin \delta 2 \\ T3X &= T3 \cos \delta 3 \\ T3Y &= T3 \sin \delta 3 \end{aligned} \qquad \text{(1)}$$

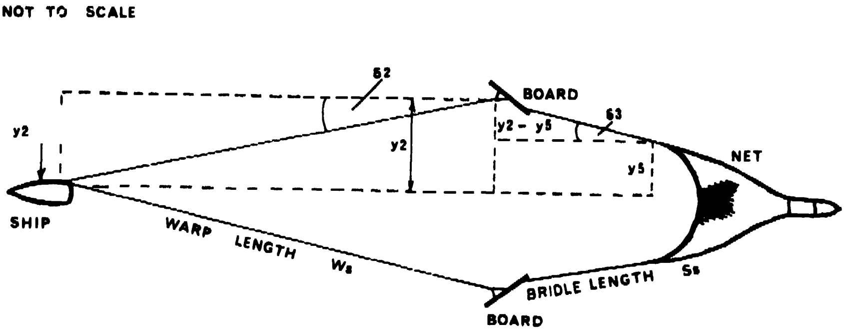
Only the horizontal wire angles, $\delta 2$ and $\delta 3$, are now needed. Figure 8 shows these angles and the approximate method of calculation using the formulae:

$$\sin \delta 2 = y2/Ws$$
$$\text{and } \sin \delta 3 = (y2-y5)/Ss \qquad \text{(2)}$$

where twice y2 is the total board spread in metres and twice y5 is the total net mouth spread in metres, Ws is the warp length in metres and Ss is the sweep length in metres

These spreads may be measured using echo-sounding type acoustic instruments mounted horizontally on the gear at appropriate points and linked to the ship either by cable or remote telemetric equipment. Alternatively, it may be necessary to use approximate values based on, for example, the divergence angle of the warps at the ship and knowledge of the length of the net headline.

Whichever method is used to measure these spreads, the values of the X and Y components of warp and bridle tension are now known.



$$\sin \delta 2 = y2 / Ws$$

$$\sin \delta 3 = (y2 - y5) / Ss$$

FIGURE 8. — Schematic presentation of a complete trawl gear showing the method of calculating the angles of warps and bridles at the otter boards.

Since the board is not accelerating, the sum of the forces in the X direction must be equal, that is:

$$\text{T2X} - \text{T3X} = \text{board drag}$$

Similarly, for the Y direction:

$$\text{T2Y} + \text{T3Y} = \text{board spreading force}$$

In a trial, the warp length was 356.5 m and this was used to tow two flat rectangular otter boards whose distance apart, or spread, was measured as 37.8 m, while the total net spread was 10.7 m. The length of the bridles was 45.7 m and the measured loads on the port side were as follows:

Warp load forward of board, T2 = 1 584 kgf

Bridle load aft of board, T3 = 975 kgf

Therefore

half spread of the otter boards, $y2 = 37.8/2 = 18.9$ m

half spread of the net mouth, $y5 = 10.7/2 = 5.35$ m

From equations (2):

$\sin \delta 2 = 18.9/356.5 = 0.053$

$\sin \delta 3 = (18.9-5.35)/45.7 = 0.275$

Hence $\delta 2 = 3.04°$; $\cos \delta 2 = 0.999$

and $\delta 3 = 15.95°$; $\cos \delta 3 = 0.962$

From equations (1):

$T2X = T2 \cos \delta 2 = 1\,584 \times 0.999 = 1\,582$ kgf

$T2Y = T2 \sin \delta 2 = 1\,584 \times 0.053 = 83.9$ kgf

$T3X = T3 \cos \delta 3 = 975 \times 0.962 = 938$ kgf

$T3Y = T3 \sin \delta 3 = 975 \times 0.275 = 268.1$ kgf

Therefore it follows that

board drag $= T2X - T3X = 644$ kgf

board spreading force $= T2Y + T3Y = 352$ kgf

These forces, as calculated, are due not only to the hydrodynamic action of the board but also to contact with the seabed if a bottom running board is being considered. But since the ground contact forces depend to a large extent on the shape of the board, on a given type of ground the calculated values of drag and spreading force are perhaps more appropriate indicators of performance than the hydrodynamic components alone.

In considering examples of otter board forces derived from full-scale trial results, it must be emphasized that there are two main sources of error which seriously affect the answers obtained:

1. The readings obtained from the measuring instruments themselves may be inaccurate by as much as 5 percent of full measuring scale in the worst cases, although the average error when a large number of readings are

considered should be less. However, the calculation of board drag is particularly susceptible to measurement errors since it is a difference between two quantities. Thus an error in T2X, say, due to measurement inaccuracy, may be of the same order of magnitude as the board drag itself. This disadvantage does not, however, apply to the calculation of board spreading force which is the sum of the two components.

2. If the otter board is either accelerating or decelerating, then the expressions for the drag and spreading forces will not apply as account should be taken of the acceleration forces. In other words, the expressions assume that the board is in static, and not dynamic, equilibrium. However, these errors are reduced by obtaining average values for the tensions in the warps and bridles over, say, 10-minute periods during which the propeller thrust is kept constant.

The following examples (see Table 1), which give a general idea of computer application, are based on trials conducted on Scottish research vessels with cambered otter boards.

The block numbers in the left-hand column refer to periods, usually of ten minutes' duration, when the gear was being towed steadily at constant propeller thrust.

All the listed parameters, except trawling speed which was measured, were calculated. Other measurements available for these calculations included the load and angles of declination and divergence at the upper end of the warps, the load at the lower end of each warp (T2) and the load at the forward end of each bridle just behind the otter boards (T3). See Figure 7.

Because of the comprehensive selection of trials measurements, the analysis was undertaken by a computer programme using a rather more complex method than that explained earlier in this section for calculating otter-board drag and spreading forces. The computer is capable of doing large numbers of calculations in a very short time and the method it uses is to calculate the shape of individual short sections of warp starting at the top, by considering the forces acting on this small length due to its motion through the water and its weight and taking account also of warp vibration. In other words, it does not assume that the wire is straight but calculates its curved shape. The difference in the answers should not invalidate the conclusions regarding the comparative performance of different types of otter boards.

The otter-board drag and spreading forces have been obtained separately for both port and starboard sides of the gear. Furthermore, there is very good agreement between the two spreading forces — on average less than 5 percent difference — while the drag forces are not in such good agreement. The reason for this was discussed above.

TABLE 1. — EXAMPLE OF THE PRINT-OUT OF COMPUTER-CALCULATED PARAMETERS OF FULL-SCALE TRAWL GEAR, BASED ON MEASUREMENTS OF TRAWLING SPEED, WARP ANGLES AND LOADS ON BOARD THE TRAWLER AND LOADS IN THE WARPS JUST IN FRONT OF, AND IN THE BRIDLES JUST BEHIND, THE OTTER BOARDS

Haul 56 WARP POSITION 3

BLOCK NO.	SHIP SPEED (KNOTS)	BOARD SPREAD M	BOARD DEPTH M	GEAR DRAG KG	NET DRAG KGS	BOARD DRAG KG PORT	BOARD DRAG KG STBD	BOARD SPREADING FORCE KG PORT	BOARD SPREADING FORCE KG STBD
1	3,50	42,2	130,1	3651,5	1506,9	327,8	480,4	384,7	328,6
2	3,80	43,6	138,6	4346,1	1791,5	419,5	466,9	452,3	434,1
3	3,20	39,2	137,1	3406,4	1390,0	323,2	439,1	316,1	278,0
4	3,60	43,8	157,8	3950,3	1562,7	359,5	482,6	419,7	371,9

Haul 57 WARP POSITION 2

BLOCK NO.	SHIP SPEED (KNOTS)	BOARD SPREAD M	BOARD DEPTH M	GEAR DRAG KG	NET DRAG KG	BOARD DRAG KG PORT	BOARD DRAG KG STBD	BOARD SPREADING FORCE KG PORT	BOARD SPREADING FORCE KG STBD
1	3,30	46,5	135,1	3512,7	1598,3	331,9	415,3	452,3	407,0
2	3,60	46,6	139,8	4320,9	1980,5	512,4	463,7	548,1	525,5
3	3,00	44,4	136,8	3263,6	1416,5	361,1	390,3	357,4	359,5
4	3,50	46,6	142,2	4174,2	1868,2	527,6	413,0	512,0	503,2
5	2,90	44,5	140,7	2925,4	1170,5	386,0	367,7	294,6	311,0

Haul 58 WARP POSITION 4

BLOCK NO.	SHIP SPEED (KNOTS)	BOARD SPREAD M	BOARD DEPTH M	GEAR DRAG KG	NET DRAG KG	BOARD DRAG KG PORT	BOARD DRAG KG STBD	BOARD SPREADING FORCE KG PORT	BOARD SPREADING FORCE KG STBD
1	3,30	39,1	135,4	3568,6	1602,9	662,3	643,0	351,8	358,1
2	2,90	38,7	127,7	3035,1	1267,2	523,1	532,8	275,8	272,7
3	3,80	39,2	142,9	4171,2	2007,9	765,2	842,5	462,9	437,5
4	3,30	38,6	148,8	3397,8	1490,0	504,2	523,5	324,4	318,2
5	3,60	38,8	132,9	3820,4	1778,6	640,3	640,3	385,8	385,8

It should be mentioned in conclusion that it is possible to gather considerably more information about the geometry of trawl gear by means of other types of (and more comprehensive) instrumentation. The collected data can then be evaluated by computer programmes and serve also to determine, for instance, whether the gear was fishing satisfactorily. As an example, the board spread of the first of the three groups of data (Table 1) would give a ready indication of malfunctioning of the otter boards.

2.2.2 Model tests

Test tanks may be used simply for observing gear behaviour without necessarily making any quantitative assessment of the forces acting on the otter board. This is mostly not sufficient for comparing the relative performance of different designs with any accuracy. On the other hand, the results of the method of calculating the forces from measurements of possibly doubtful accuracy made on full-scale otter boards under normal fishing conditions are also not always satisfactory; a particular disadvantage of this type of trial is the cost of manufacture of the test designs and also the cost of conducting the trials.

Some of the drawbacks of both these methods may be overcome by making precise measurements on model scale otter boards in either test tanks or a wind tunnel.

2.2.2.1 *Methods*

Suppose a designer wants to find out which of a selection of otter board designs is most efficient, and there is available a circulation-type test tank with an observation chamber with a cross section of 3 $\times$ 3 m. For this type and size of tank, the models should not be more than 0.6 m long to ensure that the water flow round them is not affected at all by the walls of the channel. Therefore, the designer might choose to make the model 1:5 scale if the full-size otter boards were to be 3 m long. The closer the models are in detail to the full-scale design, the more accurate the results. However, it may be practical to incorporate only the largest appendages, such as the warp bracket on a conventional flat rectangular otter board.

Each model in turn is secured at the required attitude by means of two hydrodynamically shaped struts rigidly fixed to it. The struts are attached to load measuring devices so that the total force required to hold the board in position may be calculated. Measurements of the forces are taken over a range of water speeds. The angle of attack of the otter board is then altered successively by, say, 5 degrees over the complete range of angles and the measuring procedure repeated at each attitude.

The effect of heeling or tilting the model may also be investigated by varying these two parameters separately at each value of angle of attack. Considerable reductions in spreading force can result from excessive angles of heel due, for example, to incorrect rigging of the otter board; therefore, this aspect is important.

A particular problem encountered in model testing is that the dimensions of the model are not the only quantities which must be changed in magnitude. Theoretical considerations dictate that to be sure that model-test conditions are representative of full-scale, allowances must be made for the scale factor

and for differences in kinematic viscosity of the media used, which varies with density and temperature. It is generally assumed for otter board model tests in tanks (water) and with a model scale of not smaller than about 1:8 that

$$\text{Reynold's number} \quad R_e = \frac{\text{speed} \times \text{characteristic length}}{\text{kinematic viscosity}}$$

can be neglected.

Without going deeper into the problematics of model testing, it may be mentioned that for trawl model trials in water the following modelling rules are considered a reasonable compromise (see Dickson, 1959; Schärfe, 1966). True trawl models which have exactly the same structure as the original are reduced:

— dimensions of lengths to scale;
— weights and floats to cube of scale;
— speed to square root of scale.

Forces of sheer and drag of the model, depending on water flow, will then be equal to the square of the scale, while ballast and flotation, depending on the volume, will be equal to the cube of the scale (provided they are made of material with the same specific density).

For model tests in wind tunnels, Reynold's number cannot be neglected. Consequently, such tests are more complicated and will not be discussed here. For more details of such tests, see Fischer *et al.* (1971); Stengel and Hartung (1963).

2.2.2.2 *Theory*

Before discussing how these measurements may be used to compare the performance of different otter boards, it is necessary to consider briefly the theory underlying otter board behaviour.

The efficiency of an otter board may be expressed by means of two hydrodynamic (water) forces — namely, the outward-spreading force (given the symbol L) which is at right angles to the direction of motion, and the drag force (D), or resistance to motion, which acts backward in opposite direction to motion against the pull of the boat. The forces measured in the model tests may be resolved into these components L and D.

It is a well-established fact that forces generated by water flow round a body are proportional to the density of water (ρ), the surface area (S)

and the square of the speed (V).[1] This may be expressed mathematically for otter board forces by the two equations:

$$L = \tfrac{1}{2}\,\rho\, V^2\, S\, C_L \qquad (3)$$

and

$$D = \tfrac{1}{2}\,\rho\, V^2\, S\, C_D \qquad (4)$$

where C_L and C_D are called the sheer and drag coefficients, which have no dimensions.

It is found necessary to introduce these coefficients into the equations because the forces do not depend only on ρ, V and S but will also vary with the angle of attack or attitude (Figure 4). Clearly, a board turned edgeways to the water flow will not generate the same forces as when it is faced onto the stream. The forces will also vary with the shape of the board. A flat rectangular board, for instance, will not exert the same forces as a Vee board or a cambered board of the same surface area, towed at the same speed.

Hence, the sheer and drag coefficients are functions of attitude and design. It has been shown by model tests (see Rykunov, 1971) that these coefficients do not vary significantly with towing speed.

The model tests described in this chapter can thus be used to calculate the sheer and drag coefficients for each board type over a range of angles of attack from equations 3 and 4:

$$C_L = L/(\tfrac{1}{2}\,\rho\, V^2 S) \qquad (5)$$

$$C_D = D/(\tfrac{1}{2}\,\rho\, V^2 S) \qquad (6)$$

in which expressions all the quantities on the right-hand sides are either given or measured during the tests.

The procedure which the designer follows having completed the tests is to calculate these coefficients from the above equations (5 and 6) and plot them against the angles of attack for each board. Since the coefficients are functions of attitude and shape only, the difference in level of these curves will be due, and due only, to the difference in the otter board designs. This is most important as it demonstrates that these curves can be used to compare different designs of otter board.

It is clear from equation (3) that the larger the sheer coefficient, the larger the spreading force and hence the more efficient the board will be. Similarly, from equation (4) the lower the drag coefficient, the smaller the drag,

[1] For the density of water (ρ) the value 102 (kg s^2/m^4) is commonly used.

2.2.2.3 *Examples*

Figure 9 shows the curves of C_L and C_D for models of a flat rectangular board and a rectangular board with 9 percent camber. It will be seen that the cambered otter board has a considerably higher sheer coefficient at all angles of attack but it also has a higher drag coefficient. Therefore, it is not obvious which type of board is better. In order to obtain the same value of spreading force at a given speed, the cambered board does not need to have such a large surface area as the flat board. This will also reduce the level of drag of the cambered board. If the drag is reduced below that of the flat board, then clearly the cambered board is more efficient. A simple way of taking this into account and showing graphically which board has a better performance is to plot the ratio of C_L to C_D against attitude for each case (Figures 13 and 14). The cambered board is, in fact, seen to have higher C_L/C_D values over the whole range of attitudes.

The curves for various types of otter boards both in midwater or in ground contact (Figures 9, 10, 11, 12) are based on several sources of this type of information from various countries (see Fischer *et al.*, 1971; Rykunov, 1971; Stengel, 1963).

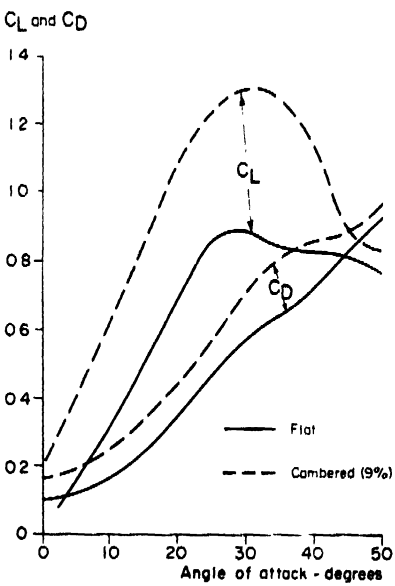


FIGURE 9. — Sheer and drag coefficients of rectangular flat and cambered (9 percent camber) otter boards in ground contact in relation to angle of attack.

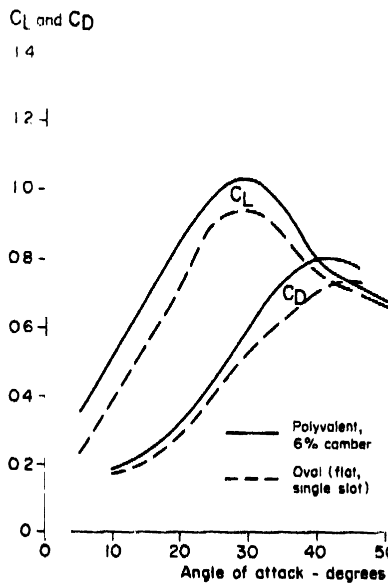


FIGURE 10. — Sheer and drag coefficients of polyvalent (6 percent camber) and oval flat single slot otter boards in ground contact in relation to angle of attack.

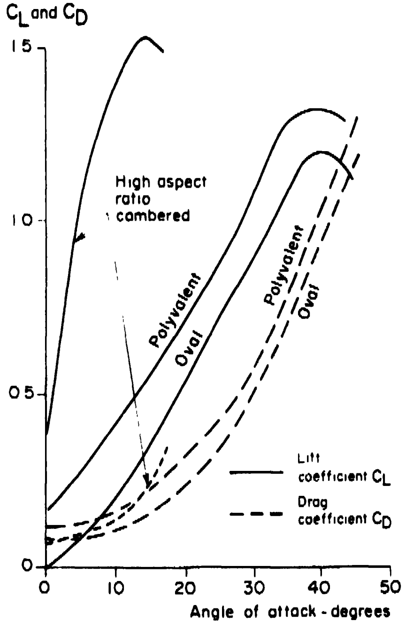


FIGURE 11. — Sheer and drag coefficients of oval flat, polyvalent and high aspect ratio rectangular cambered (Süberkrüb type) otter boards in midwater in relation to angle of attack.

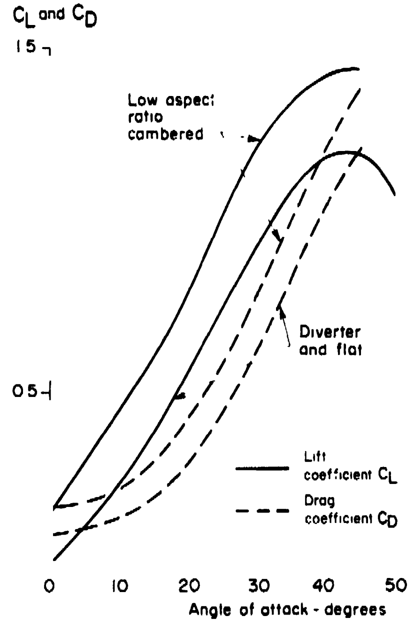


FIGURE 12. — Sheer and drag coefficients of low aspect ratio rectangular cambered, rectangular flat and diverting depressor otter boards in midwater in relation to angle of attack.

Not all the tests give precisely similar results, but the curves presented are most nearly appropriate to full-scale conditions, that is, in some cases heel angle has been taken into account.

It should be pointed out that any otter board has a restricted range of values of attitude at which it can operate. Only this range needs to be considered, as it is usually not possible to induce greatly different attitude angles by, for example, changing the wire attachment points or board weight. This is due partly to the lack of stability of the board brought about by any such changes.

The inclusion of one or more slots in a board enables it to operate at a reduced angle of attack. A similar but more pronounced effect is obtained by the use of camber. Thus, in normal trawling a flat board will usually have a range of attitudes between 35 and 45 degrees, depending on speed and seabed conditions, and an oval slotted board, a diverter or a Vee board usually operate at angles between 30 and 40 degrees. Cambered rectangular

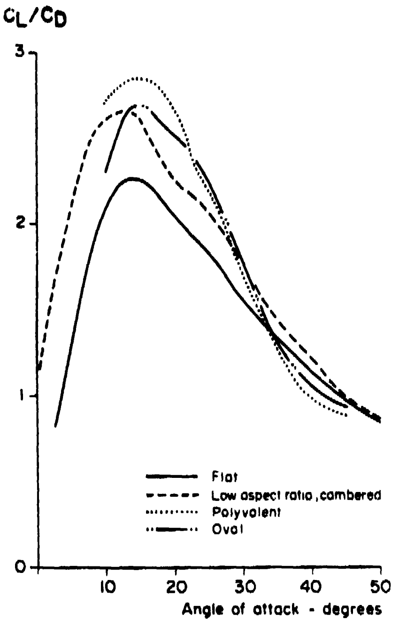


FIGURE 13. — Otter board efficiency indicated by the ratio of sheer to drag coefficients in relation to angle of attack for rectangular flat, low aspect ratio rectangular cambered, polyvalent and oval flat otter boards in ground contact.

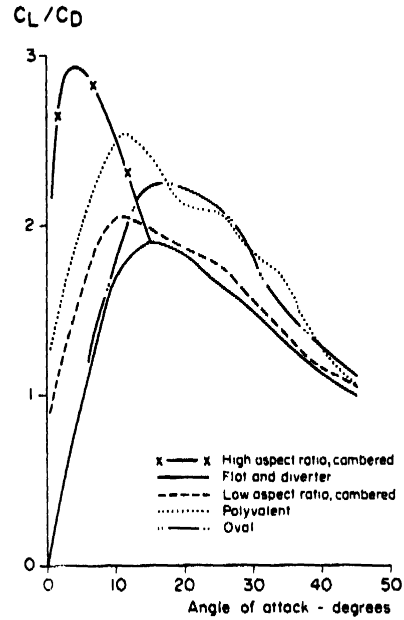


FIGURE 14. — Otter board efficiency indicated by ratio of sheer to drag coefficients in relation to angle of attack for rectangular flat and diverting depressor, low aspect ratio rectangular cambered, polyvalent, oval flat and high aspect ratio rectangular cambered otter boards in midwater.

and polyvalent boards of low aspect ratio have attitudes of 25 to 35 degrees, but high aspect ratio cambered boards, specifically for midwater trawling, will operate at only 15 to 25 degrees. Furthermore the latter will have some variation of heel angle with speed due to the warp attachment point usually being positioned about 5 percent of the height above the centre line. Most otter boards operate at angles of heel between +10 and −10 degrees, although the diverting depressor is a special case, as it is by design very stable. A Vee board tends to operate with the top half vertical. Board attitudes and heel angles will alter when changing from midwater to bottom trawling in cases where there is significant ground contact, for instance, oval and flat rectangular doors will change their orientations, although by differing amounts due to the different keel shapes. The attitude angles will, however, probably remain within the ranges quoted earlier.

2.2.2.4 *Accuracy and limitations*

Curves such as those shown in Figures 9 to 12 can be obtained only from model tests and it is important to know how representative these models are of full-scale otter boards.

Clearly, the models cannot always be precise replicas of their full-scale counterparts, but differences in detail such as surface roughness, number of bolts and so on will not invalidate the comparison. Figure 15 shows the small difference made to the variation of C_L in the attitude of a flat rectangular board close to the seabed when the model has all the appendages such as warp bracket attached compared to when it is bare. Of course, the appendages which cause much of this difference (warp bracket, stiffening plates and keel) should be incorporated in the model.

There are, however, two important possible causes of discrepancy between model and full-scale results:

(*a*) When the otter board is in ground contact, a model test cannot reproduce the ground forces which act on the board keel as it scrapes along the seabed. The test will simulate only the hydrodynamic forces for this case — that is, the model is placed very close to, but not touching, the floor of the test area so that the water (or air) flow round the model is modified appropriately by the presence of the seabed. But the actual forces due to sand piling up along the front face of the board, for instance, are not accounted for. These forces may increase or reduce the efficiency of the board, depending upon its shape and the nature of the seabed.

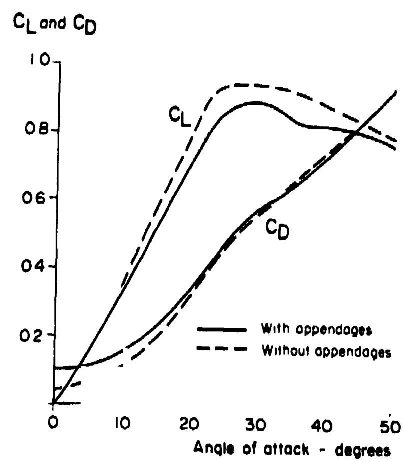


FIGURE 15. — Effects of otter board appendages on the coefficients of sheer and drag found in model tests with rectangular flat otter boards.

(*b*) There may be what are known as "scaling effects," that is, the very fact that the model requirements for design and speed are basically incompatible and the practical compromises (see 2.2.2.1) have shortcomings so that the models may behave in a different way from the full-scale versions. It is beyond the scope of this document to pursue this complex subject further. Textbooks specifically concerned with model testing give full explanations. It should be mentioned that the scaling effect increases with decreasing model scale.

2.2.3 COMPARISON BETWEEN FULL-SCALE AND MODEL TESTS

Before an attempt is made to compare model and full-scale tests, it is necessary to make one very important assumption: that, under normal fishing conditions, a full-scale otter board does not significantly change its angle of attack when *towing speed only* is changed. This simplifies the situation a great deal as it follows that the sheer and drag coefficients will be constant with speed. For example, a flat board might be assumed to have a constant angle of attack of 43 degrees. Referring to Figure 9, this means that $C_L = 0.81$ and $C_D = 0.79$ for all speeds.

In order to compare model and full-scale results, consider equation (5) above. This may be written

$$(L/S) = \tfrac{1}{2}\, \rho\, C_L\, V^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Therefore when spreading-force/board area (Y/S), is splotted against speed squared, the slope of the resulting straight line graph will be equal to $\frac{1}{2}\rho$ CY and thus proportional to the sheer coefficient (CY). The equation also shows that this straight line should pass through the origin.

Similarly, equation (6) involving board drag (D) may be written

$$D/S = \tfrac{1}{2}\, \rho\, C_D\, V^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

These two plots of spread and drag per unit area against speed squared are most useful for comparison of full-scale trials and model tests and can also be used to compare the performance of different designs of otter boards.

First, the experimental points from trials are plotted on a graph of L/S or D/S against V^2. Then a straight line is drawn through the origin having a slope equal to $\frac{1}{2}\rho C_L$ or $\frac{1}{2}\rho C_D$ respectively. (When the force per unit area is in kgf per m^2 and the speed is in knots, $\frac{1}{2}\rho$ has a value of 13.5.) Appropriate values of C_L and C_D for calculating the slope of these theoretical lines may be obtained from Figure 9 or 10 by assuming a value

of attitude. However, it should be remembered that in practice the attitude angle may not have precisely the assumed value; and, more important, the heel angle may alter to a significant degree if, for instance, the rigging is changed. Therefore, it should not be expected that the theory line coincides exactly with the full-scale experimental points.

This is an important point which should be stressed again; namely, that the examples quoted in this manual will not necessarily confirm or disprove that there is precise agreement between model and full-scale tests because scatter of experimental data and errors in the assumptions regarding attitude and heel of the otter board may mask the agreement. However, the examples do show that there is broad agreement and also point to other reasons for discrepancies, such as changes in warp length.

2.2.3.1 *Midwater trawling*

The graphs for *spread force per unit area*, of which Figure 16 is an example, show quite good agreement between theory and full-scale trials. The difference in level between the theory line and a mean line (not shown) through the points is on average 11 percent. The equivalent number for

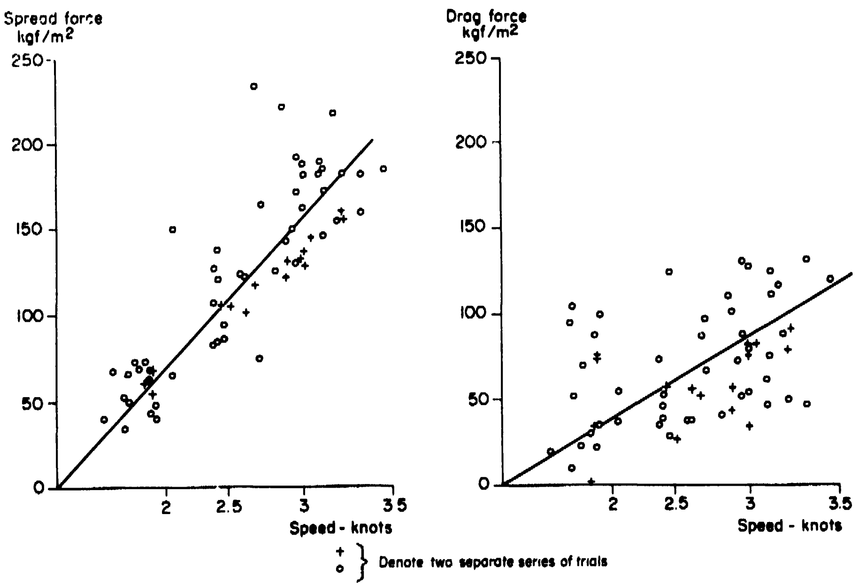


FIGURE 16. — Example of the relation between theory and trials data for predicting the performance of a high aspect ratio rectangular cambered otter board (the straight line is derived from model tests and theory and does not indicate the means of the measured data).

the *drag per unit area* graphs is larger and of course the scatter of points about the mean lines is very much more than for the spread force graphs. This is expected, since drag is calculated from the difference of two quantities and is therefore more sensitive to errors in either of them. Furthermore, the scatter is exaggerated in these particular trials because the load cells available for measuring the wire loads forward and aft of the otter board were not suitable for such small loads because they had too large a measuring range (3 000 kgf); therefore, an error of 2 percent of full-scale represented an error of 40 percent in the calculation of drag.

It is expected that the scatter of points, and also perhaps the percentage differences quoted above, would be reduced if more sensitive measuring instruments were used. In addition, when more experience has been gained in measuring attitude angles, in particular heel angles, and in observing their effect on board performance, more realistic values for the sheer and drag coefficients may become available.

Up to this point, no mention has been made of ways of comparing the performance of the different designs of otter board. For this, both spreading force and drag must be considered. For instance, an otter board with a large drag as well as a large spread may be less efficient than one with low drag and mediocre spreading force. Therefore, the ratio of spreading force to drag is a good indication of board efficiency. Relevant data can be taken from Figures 9 to 12, 16 to 18 and Tables 4 and 5.

2.2.3.2 *Bottom trawling*

As mentioned above, model tests in a wind tunnel or flume do not take into account the ground contact forces between otter board and seabeds. There is, therefore, a respective discrepancy between the results of such model tests (theoretical equation) and experimental full-scale trials (Figure 17). Accordingly, in midwater trials model-test results are in reasonably good agreement with theory and full-scale measurements. For demersal otter boards, the magnitude of the discrepancy between model and full-scale tests and the pattern of measuring points can give some information about the nature of the ground-contact force for each type of otter board.

Investigations show that in the majority of cases, regardless of board shape, the full-scale experimental values of spread force/area and drag/area are greater than can be predicted by model tests and theory (e.g., Figure 17). This is as expected, since the debris which accumulated along the inside bottom edge of the board as it moves along the seabed tends to prevent the board from moving inward, that is, it increases the outward spreading force but even more, the drag. This in general will result in an overall decrease in efficiency in terms of the ratio of spread to drag.

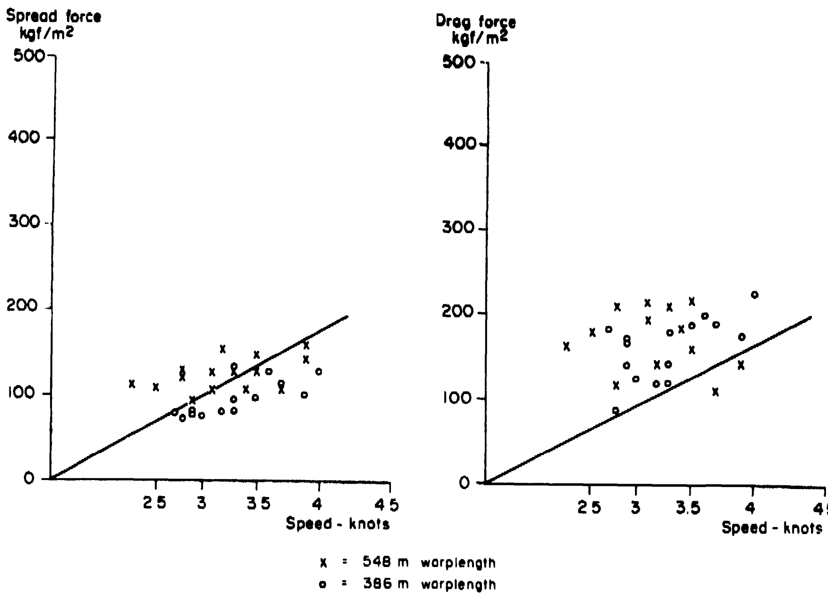


FIGURE 17. — Example of the relation between theory and trials data for predicting the performance of a rectangular flat otter board (the straight line is derived from model tests and theory and does not indicate the means of the measured data).

However, in some cases, for instance for flat rectangular otter boards, the ground-contact force is essential in order to obtain steady motion through the water. Off the seabed, flat boards are subject to large fluctuations in heel and attitude angles which drastically reduce their efficiency. On the other hand, a Vee board is rigged in such a way that only a small ground-contact force is required to retain equilibrium in a stable position. If the board lifts, the hydrodynamic force on the lower surface reduces more than on the upper surface, creating a turning movement which returns it to its original orientation. For this reason, Vee boards are considered to be good on rough ground, as they tend to ride over obstacles easily.

There are disadvantages in using too short a warp length in relation to water depth (i.e., less than 3:1). The vertical component of warp tension increases as the warp length is shortened so that the otter board is finally lifted off the seabed. Also, ground contact and thus the stability and magnitude of the spreading forces are reduced and consequently the otter board and net-mouth spreads will decrease. Furthermore, the otter board will stir up less mud, which may lessen the effects of herding certain fish toward the mouth of the net. Low warp length-to-depth ratios, which

may be necessary for trawling in deep water, therefore, require particularly heavy otter boards or an adjustment of the warp brackets for outward heel, that is, the point of attachment of the warps must be well below the centre line of the otter board.

In the same sense, high warp length-to-depth ratios allow the use of lighter otter boards with little or no outward heel and are, therefore, indicated for soft bottom. Warp length-to-depth ratios of 4:1 to 6:1 are quite common. When trawling in very shallow water (20 m depth and less), the warp length-to-depth ratio may become 10:1 and even more. This

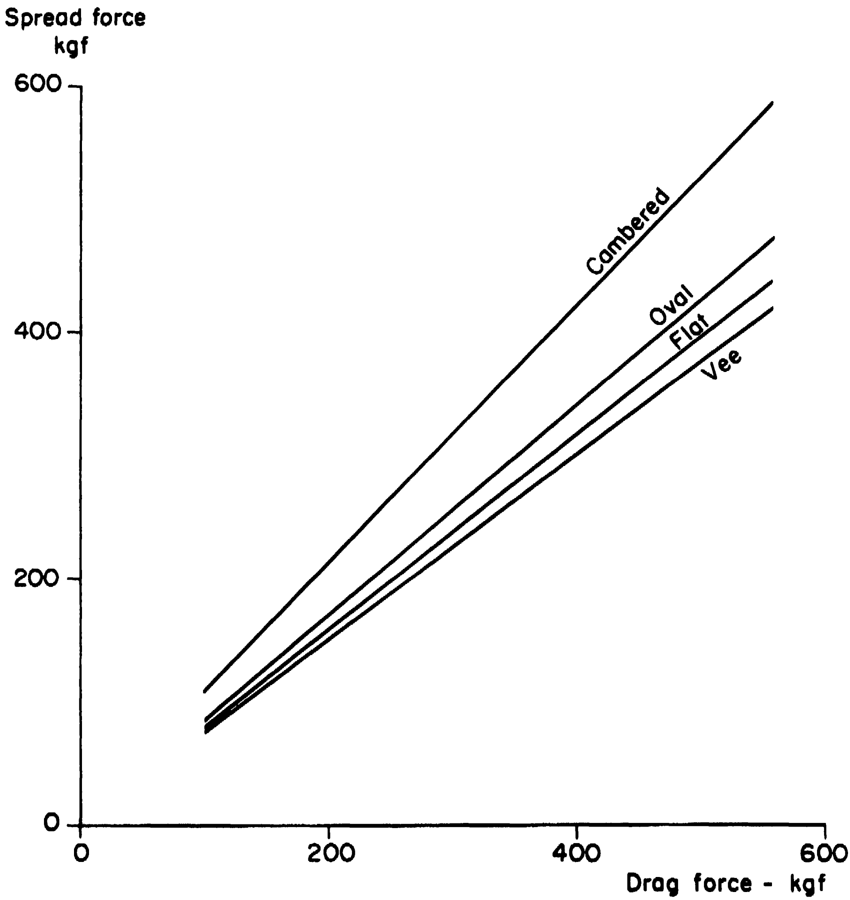


FIGURE 18. — Relations between spread and drag forces of rectangular flat and cambered, oval flat and Vee type otter boards in ground contact.

is because a certain minimum length of warp is required in relation to the length of bridles, the type of net, and the spreading force of the otter boards to ensure the proper width of the net mouth. In extreme cases, the upward component of the warp tension may become zero or even negative, as when the warp in front of the otter board touches bottom. This is undesirable because it causes wear to the warps and may also reduce catching efficiency by scaring bottom fish away from the course of the trawl. Experienced trawl skippers therefore keep this under observation by checking whether and what length of the last part of the warps in front of the otter boards have become "shiny" (polished) from bottom contact and adjust the warp length (and/or bridle length) accordingly.

Figure 17 demonstrates very well the loss in spreading force when warp length is changed. However, in these examples there are other factors influencing the behaviour of the boards in addition to those mentioned above. It is interesting to note (Figure 17) that mean lines drawn through each set of points (x and o) would cut the vertical axis at points well above the origin, demonstrating that there is static friction to be overcome in each case.

It might be expected that the oval type of otter board would have lower ground contact forces because of its rounded keel. The Vee type otter board was found to have greater oscillation of sheer and drag, owing to the turnable bracket which gives the board freedom to heel. Consequently, Vee boards tend to heel inward, which creates some upward sheer, but this is counteracted by the generally heavier weight of this type of otter board.

As a summary of many measuring trials, average relations between spread and drag forces per unit area are given in Figure 18 for the main types of commercial bottom type otter boards to give an idea of their comparative performance.

CHAPTER 3

COMMERCIAL PRACTICE IN THE MATCHING OF OTTER BOARDS TO NETS AND TRAWLERS

Otter boards, which account for approximately one fifth to one fourth of the total drag of trawl gear, also directly influence the geometry of a trawl and consequently the overall drag of the gear. It is, therefore, vital, once having established the desirable net parameters, to choose the size of otter board which will ensure the best possible use of the available towing power consistent with fishing efficiency.

Selection of otter board size to match a particular trawler and available trawls is a constantly recurring problem. If sufficient information is available, it is possible, by calculation, to predict the required board size (see 2.2). All too often, sufficient information is not available and it is expedient to seek a solution by considering what is general commercial practice based on experience of existing fisheries.

By using the graphs presented here, which are based on commercial practice, the approximate size and weight of otter boards required to match a trawler of a given main engine (hp) can be selected. These graphs have been collated by taking into account a large sample of the trawl gear used by a range of trawlers operating in developed fisheries and by combining this with information supplied by commercial otter board manufacturers. In order to be sure that the graphs are not too narrowly based, only otter boards which are in either international or popular use are included in the survey. The information should, however, be treated with care. The lines are averages and as much as 10 percent variation in size and weight is common, even on trawlers of similar size fishing on the same grounds.

The following remarks may help to clarify the factors which affect the correct application of the information. In using the graphs, it should be assumed that the trawlers represented therein are of standard design and capable of towing gear at an average speed of up to 4 knots. Any known data which affect the specific trawler's towing performance (e.g., torque, propeller or hull form) should be taken into account. For example, if precautions have been taken to increase the towing power available by use of a variable pitch propeller or a propeller nozzle, a more powerful

otter board than indicated can be used. Cognizance should also be taken of the required net geometry, speed variation and the nature of the bottom in the area to be fished, as discussed below.

In order to facilitate presentation, and for ease of study, the otter boards represented have been classified as those used for bottom, pelagic (mid-water) and dual-purpose trawling. A fourth section of the chapter deals with the empirical relationship between otter board area, twine surface area of the trawl and towing power (hp) of the trawler. In some cases where there is a wide variation in the area and weight of the otter boards within the countries selected for comparison, average figures for the countries are also given. To facilitate comparison, combination graphs have also been included showing new designs with traditional ones (Figures 23 to 25). Table 3 shows for comparative purposes the common board areas and weights for trawlers of 400 and 1 000 hp. It must be stressed that the purpose of the combination graphs and the table is to emphasize the relative areas and weights of the different types of otter board and thus to give some perspective to their selection.

3.1 Bottom trawling

Three types of otter board are represented in this section. These are standard flat boards in common use since the advent of trawling; flat oval boards, which were developed and are popular in the U.S.S.R. and seem to be increasingly adopted by other fisheries; and Vee-form boards, still more recently developed, and already used extensively. In selecting any one of these, consideration must first be given to the ground conditions in the area to be fished. It is claimed that flat oval boards can ride over ground obstacles more easily than flat rectangular boards because of their curved leading edges. The design of the Vee board also has advantages for rough bottom and in addition is less liable to dig or to become fast in soft ground.

In dealing with flat rectangular boards, comparison has been made between the otter boards used in France and in the United Kingdom (Figure 19). It will be noted from the graphs that the French otter boards (medium-distance trawling from Boulogne-sur-Mer; Portier, 1967) are smaller in area and lighter in weight. This is indicative of the fact that lighter gear and warps of a lesser diameter are used by these trawlers. A line is included showing an easily remembered approximation of board weight: 1 kg per hp of the towing vessel.

Flat oval boards are used in a variety of forms. They can be either plain, single-slotted or multislotted. Advantages to be gained by using

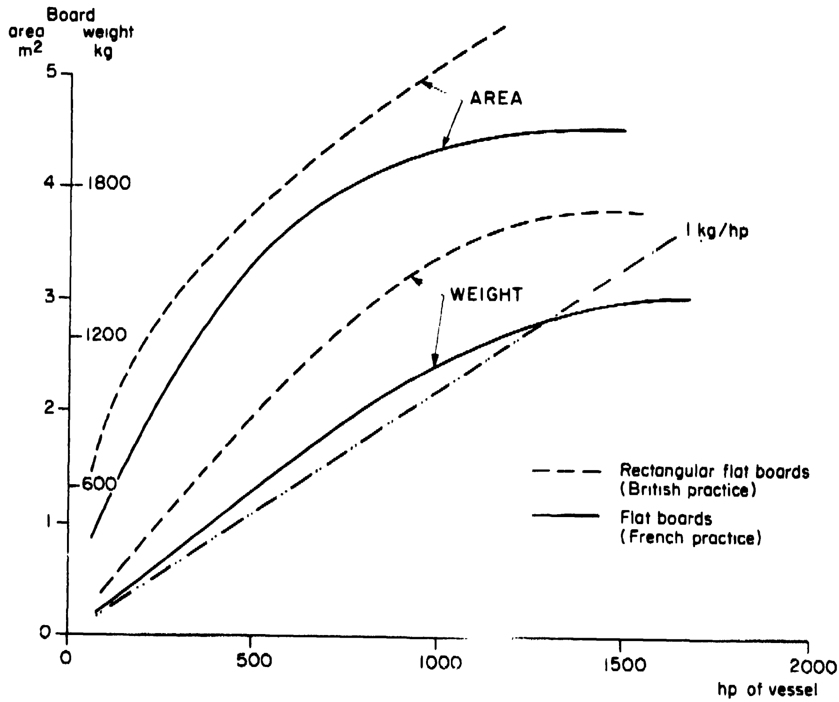


FIGURE 19. — Common size and weight of rectangular flat otter boards in relation to hp of trawler.

slotted boards have not been properly established, although there are indications of an improvement in the drag-to-spreading-force relationship. The boards represented in Figure 20 are of the single-slot type and are of Norwegian manufacture. A comparison could not be obtained with such boards of different manufacture.

A comparison has been made between the Vee boards used by Danish and British fishing fleets (Figure 21). As development of the inshore fleets of both countries has followed a parallel course, there is little apparent difference between the size and weight of the boards used.

3.2 Midwater trawling

Attempts at one-boat midwater trawling are recorded as long ago as 1903. Through the years, various otter board ideas have been tried, but with little success because of problems of stability and handling.

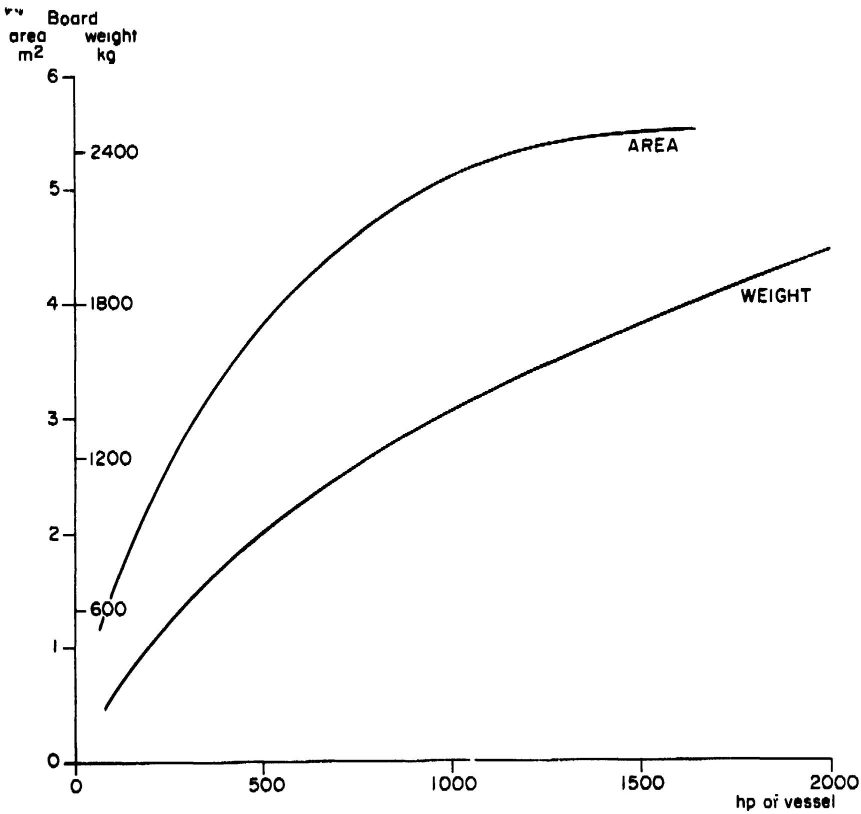


FIGURE 20. — Common size and weight of oval flat otter boards in relation to hp of trawler.

The first real commercial success must be attributed to H. Larsson of Sweden, who in the 1940s developed a midwater otter board of curved section, not unlike the Süberkrüb board. This otter board was fished commercially in Sweden for several years until it was superseded by the Wing otter board, a further development by Larsson. This new design was considered to perform better than the previous one and to be more flexible in operation. Improvements included a ring device providing alternative towing points, which allowed some measure of depth regulation. Although quite successful, this otter board has as yet received little acclaim outside Swedish fisheries. In the United States, a board was developed for use with the Cobb pelagic trawl, but gained little prominence elsewhere. In Canada, Barraclough & Johnson had limited success locally with an

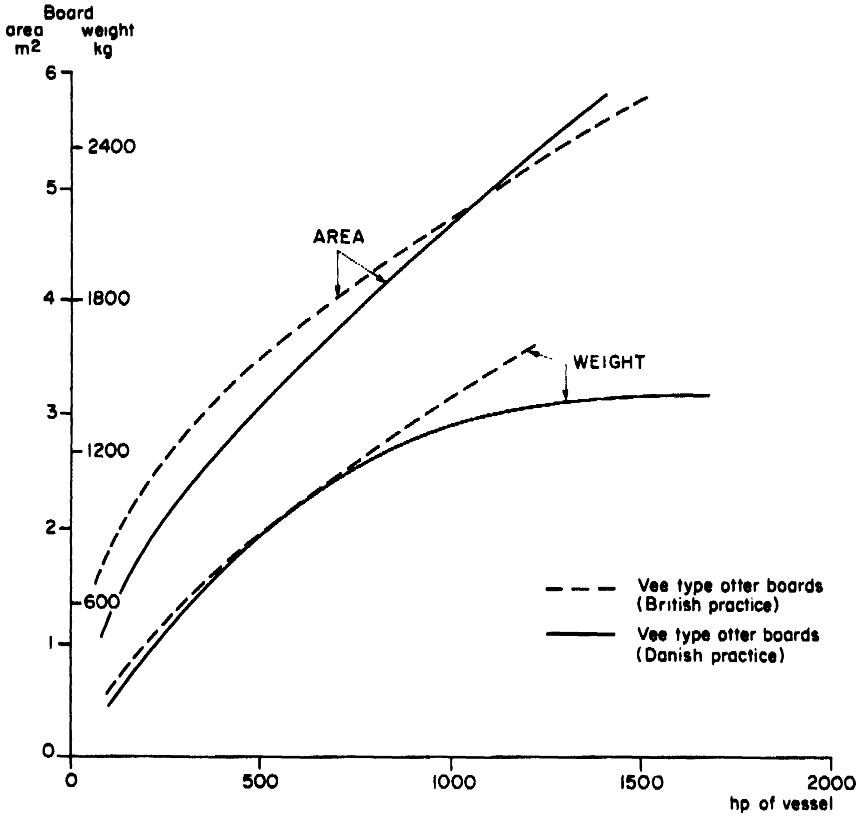


FIGURE 21. — Common size and weight of Vee type otter boards in relation to hp of trawler.

otter board developed by them. In other countries such as the U.S.S.R. and Japan, the experience has been similar. The important feature of all these experiments was the adoption of a curved or cambered profile for greatly improved efficiency and, in particular, reduced drag required for the best utilization of available power to tow the largest possible net at adequate speed.

The most successful midwater otter board, now widely used internationally, is the Süberkrüb board, developed in Germany in the 1930s. Originally intended for bottom trawling, it is both stable and versatile in midwater operation and can be fished from trawlers through the complete range of available horsepower. It has, therefore, been selected as representative of this section (Figure 22).

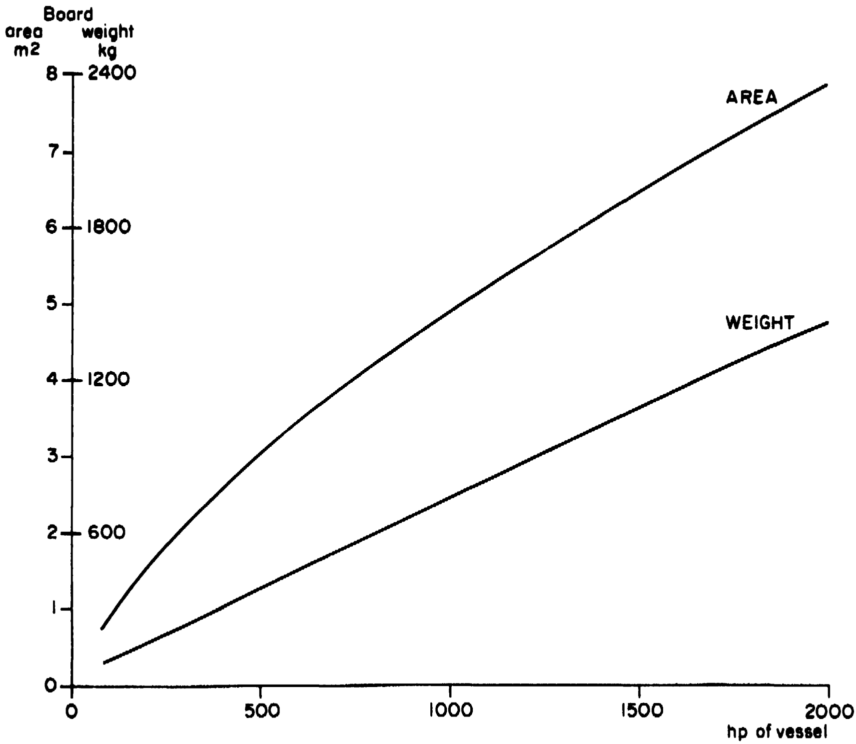


FIGURE 22. — Common size and weight of high aspect ratio rectangular cambered otter boards (Süberkrüb type) for midwater trawling in relation to hp of trawler.

3.3 Dual-purpose trawling

Not surprisingly, many fishermen have tried to create a useful midwater otter board by simply lifting standard flat otter boards off the bottom, that is, by shortening the warps and/or adding flotation to the top of the board itself. This had partial success in a rather limited field, but the rather poor hydrodynamic performance of these simple bottom otter boards in midwater precludes this method other than as a temporary measure. Improvements to performance are possible if the weight, including centre of gravity, the backstrop and warp take-off positions are adjusted, although problems of stability and the basic inferiority to cambered profiles still remain. Various compromise solutions are known. The otter boards described below seem to come nearest to a solution of the problem.

Polyvalent otter boards and stabilized diverting depressors, both comparatively recent developments, are manufactured to perform the dual purpose of "on" and "off" bottom fishing. Trials in various fisheries have proved that they do fulfil this need to a certain extent and their high initial cost is partly offset by the fact that different types of boards are not needed for the two sorts of fishing if performance requirements are moderate. In the bottom-running condition, the performance of the polyvalent board compares favourably with other types of bottom otter boards. The diverting depressor has about the same sheering performance as a conventional flat rectangular otter board with differences due to the fact that the board itself does not have bottom contact. In midwater they are

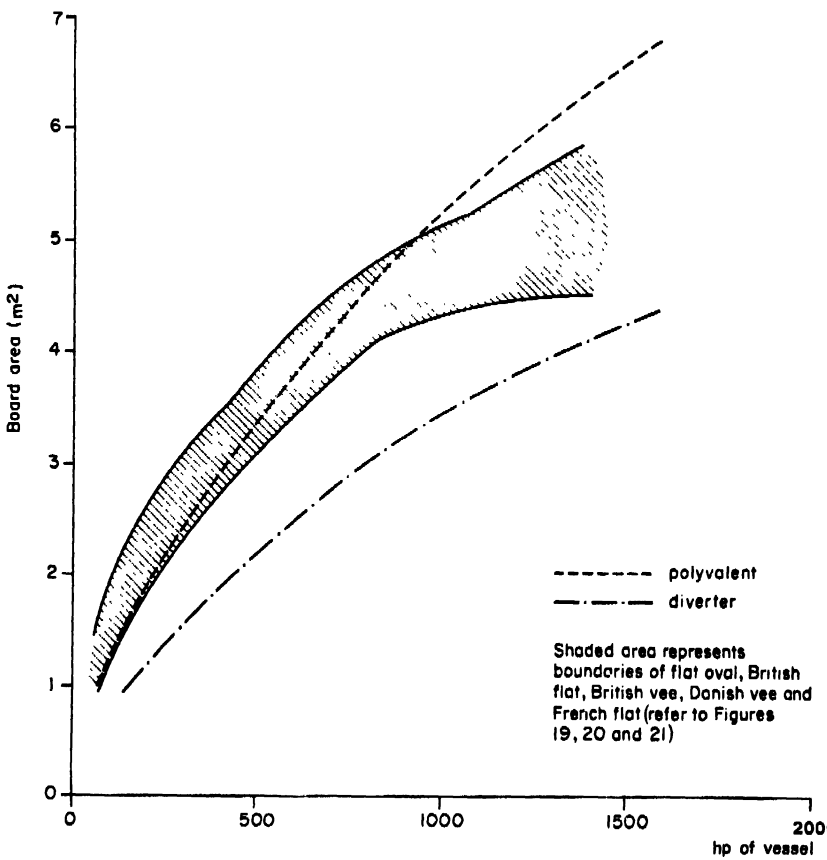


FIGURE 23. — Size of polyvalent and diverting depressor otter boards in relation to hp according to manufacturers' recommendations.

both less efficient than Süberkrüb boards, particularly the diverting depressor. With polyvalent boards the correct warp take-off position for bottom or midwater trawling has to be selected before fishing commences, whereas no adjustments are required to the stablized diverting depressors; these can be fished in either condition during the course of a tow. The sizes and weights of the boards shown in Figures 23 and 24 are average figures generally in line with those recommended by the manufacturers. Instrumented engineering trials on commercial and research vessels have shown these to be of the right order.

It should be mentioned that high aspect ratio (about 2:1) cambered otter boards of the Süberkrüb type have been extensively tested for dual-purpose trawling with very promising results. They are also extensively used for bottom trawling in the Japanese fishery on trawlers ranging widely in size

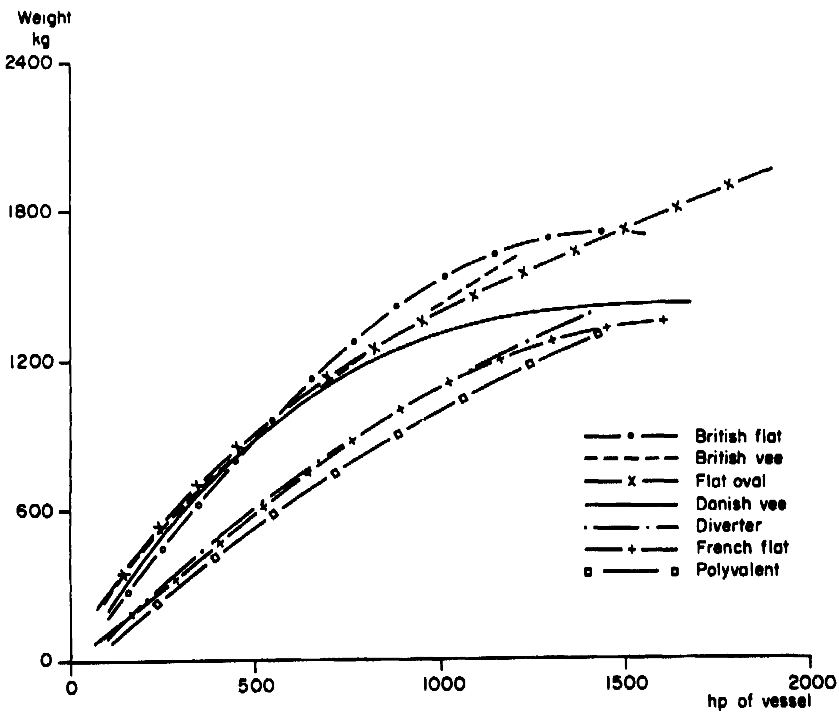


FIGURE 24. — Common weights of various otter board types in relation to hp of the trawler (diverting depressor and polyvalent otter boards according to manufacturers' recommendations; all others according to common use).

and power. Because of some operational implications, they are, however, not adopted so far for commercial bottom or dual-purpose trawling elsewhere. Because of its clearly superior efficiency, this type of otter board deserves more attention, particularly for trawlers whose towing power is the main limiting factor.

3.4 Otter board, trawlnet and towing power

A number of empirical "laws" have been deduced by comparing otter board sizes, twine surface of the trawlnets and towing power (hp) of the towing vessels. Such an analysis of the trawl geai and trawlers operating from Boulogne-sur-Mer has been of considerable help to this fishery (Portier, 1967).

An approximation to the twine surface area of a trawlnet can be obtained from the following formula:

$$TS = \left[\frac{N+n}{2} \times H\right] \times \quad a \times d \,|\times 10^{-6}$$

TS = surface area of netting twines in m^2
N = number of meshes across front edge
n = number of meshes across aft edge
H = number of meshes in depth
a = bar length of mesh in mm
d = diameter of netting twine in mm

The formula is applied to each section of the net and the sum totalled to give the overall netting twine surface area for the complete trawl.

Figures 27 and 28 show the relationship that exists for French and British trawlers and can be used to establish the approximate gear suitable for a trawler of a given towing power (hp). The slightly higher values for the twine area of the British bottom trawls is partly due to the fact that they include the cod end, which is not the case with the French trawls.

When considering the values given in Table 3, it must be kept in mind that they are representative only for certain fishing conditions (i.e., predominantly rough grounds and a wide depth range). For soft grounds and/or shallow waters, otter boards of much lighter weight per unit area are used in well-established trawl fisheries, (e.g., in the Mediterranean and for coastal shrimp trawling).

TABLE 2. — EXAMPLE FOR THE CALCULATION OF THE NETTING TWINE AREA OF A BOTTOM TRAWLNET (SPECIFICATIONS GIVEN IN FIGURE 26).

1	2	3	4	5	6	7	8	9
Net parts	Number of parts	$\frac{N+n}{2}$	H	$\frac{N+n}{2} \times H$	a	d	4 a d	$\frac{N+n}{2} \times H \times 4\,ad \times \text{parts} \times 10^{-6}$
					.... *Mm*			... M^2 ...
Top wings	2	23	34	782	75	2.03	609	0.952
Square	1	162	29	4 698	60	2.03	487	2.289
Baitings	1	138	117	16 146	40	2.03	324	5.244
Cod end (double)	2 (double) × 2	60	60	3 600	40	2.44	390	5.620
Lower wings	2	13	60	780	75	2.44	732	1.142
1st belly	1	126	27	3 402	60	2.80	672	2.286
2nd belly	1	111	76	8 436	40	2.44	390	3.293
						Total		20.826

TABLE 3. — EXAMPLES OF OTTER BOARD SIZES AND WEIGHTS COMMONLY USED IN THE NORTHEAST ATLANTIC AND THE NORTH SEA

Type of otter board	400 hp		1 000 hp	
	Area	Weight	Area	Weight
	M^2	*Kg*	M^2	*Kg*
Flat oval	3.0	670	5.2	1 380
British flat	3.4	700	5.1	1 530
French flat	2.9	470	4.4	1 110
British Vee	3.2	750	4.8	1 410
Danish Vee	2.7	720	4.7	1 310
Polyvalent	2.9	420	5.3	980
Süberkrüb	2.6	250	4.3	700
Diverter	1.9	520	3.4	1 110

3.5 Guidance for selection of otter boards

Before any practical use is made of the graphs (Figures 19 to 25, 27 and 28), it is essential to consider precisely what information they represent. For those board types where a considerable amount of published information was available or where verbal data from individual fishing companies and fishermen could be readily obtained, specific graphs showing typical otter board size and weight are given. Average figures have been deter-

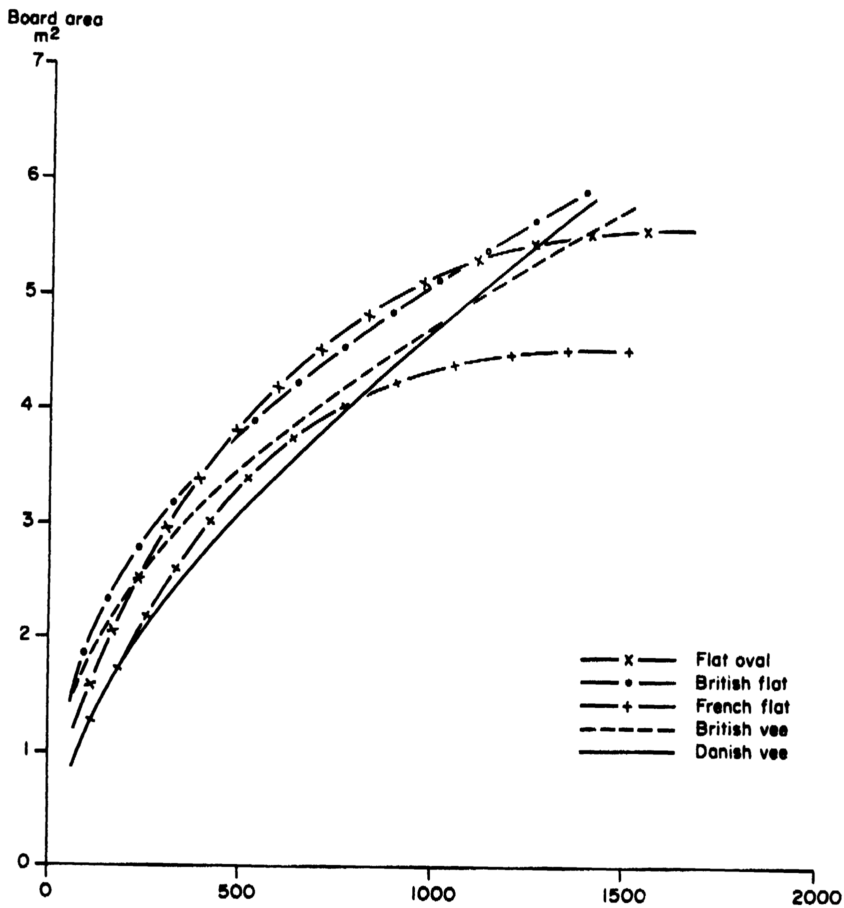


FIGURE 25. — Common area of otter boards in relation to hp of trawler according to commercial use.

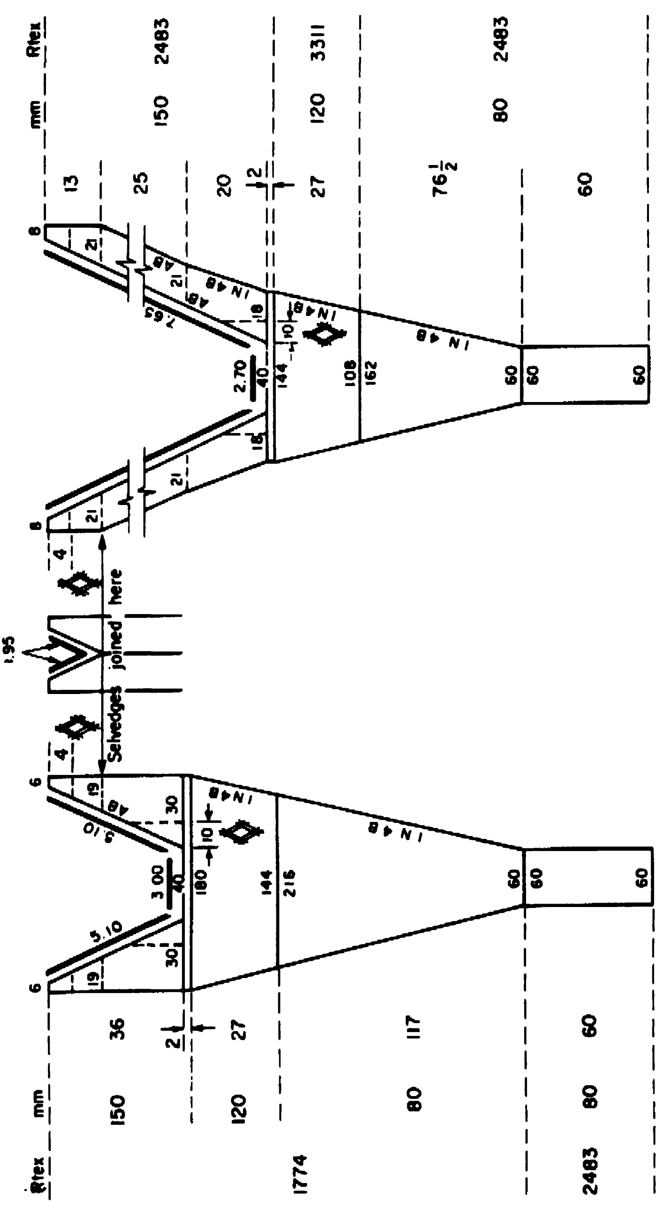


FIGURE 26.—Construction drawing of the bottom trawlnet used as an example for calculating the twine surface area

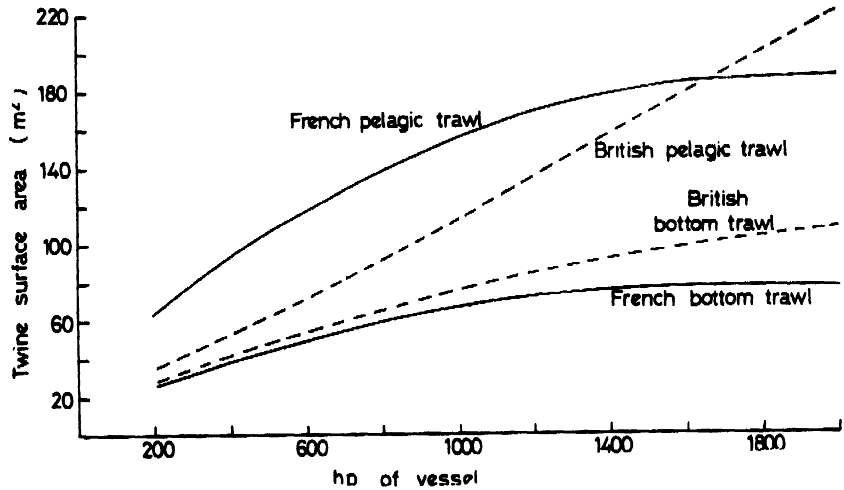


FIGURE 27. — Twine surface area of some typical otter trawlnets in relation to hp of trawler.

mined (the scatter is as much as ± 10 percent) and no attempt has been made to modify these values to take account of expected performance except insofar as this should have influenced the manufacturers' recommendations. It should be remembered that this data is based on North Atlantic practice.

In some cases, the average commercial practice was found to be consistently different in the two countries considered. This applies to both flat and Vee type otter boards and separate curves were, therefore, drawn. In such cases, practice in other countries can be assumed to be within the extremes plotted.

Figures 23 and 24 can be used to compare the sizes of new types of otter board (polyvalent and diverter) with more traditional otter boards as far as matching to towing power is concerned. Again, the manufacturers' recommendations for the new types have not been modified according to instrumented trials. However, Figure 15 can be consulted in this context.

The graphs (Figures 27 and 28) relating net twine surface area to towing power and otter board size require the calculation of the surface area of the net under consideration as indicated, and can mainly be used as a further check on otter board size. The relationship shown between net twine area, towing power and otter boards is based on standard flat and Süberkrüb otter boards (gear of typical French and typical British practice are treated separately).

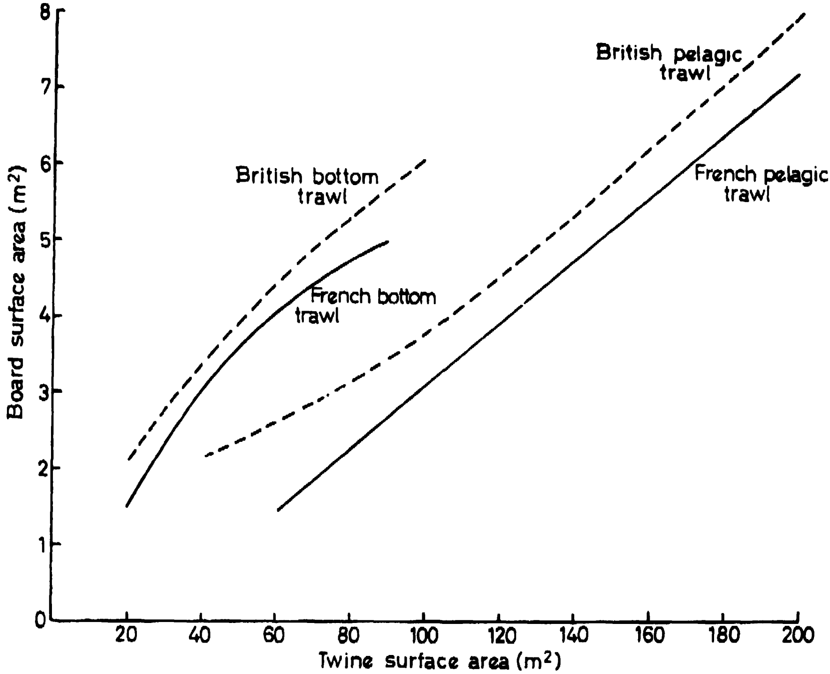


FIGURE 28. — Common relationship between size of otter board and twine surface area for some typical trawl gear.

It is not recommended that the graphs be interpolated to derive the relative sizes of otter boards of different types to match a given net twine surface area. When this is necessary, it is considered more appropriate to work out the size of a standard flat board and then refer to the relevant figure, which gives the spreading force (according to shape) of the specific otter board type desired.

Example 1

What size of Vee type otter board is normally used for a vessel of 300 hp?

Method. Referring to Figure 21, it can be seen that an otter board of between 2.3 and 2.8 m² is adequate. Since the Danish fishing tends to be rather specialized, it is suggested that as compromise a value of 2.7 m² should he chosen in the absence of further information of fishery requirement.

Example 2

Standard flat otter boards for bottom trawling are required for a vessel of 400 hp. Light warp is used and the twine surface area of the net (calculated according to the rules given) is 44 m^2.

Method. (*a*) Refer to Figure 19 and read off otter board area: French practice would be 2.9 m^2 and British practice 3.4 m^2.

(*b*) Refer again to Figure 19 and read off otter board weight: French practice would suggest 475 kg and British practice 705 kg.

(*c*) Refer to Figure 28 and read off otter board area: French practice would be 3.25 m^2 and British practice 3.6 m^2.

The reference to light warps suggests that the fishing requirement is nearer to French practice (commonly diameter of main warps used on French trawlers is 2 to 3 mm less than the British equivalent). Thus, it seems reasonable to bias the choice of the otter board toward French practice. A suitable compromise value would be 3.25 m^2. By referring again to Figure 19, a 3.25 m^2 otter board has a weight of approximately 550 kg if the French practice is assumed.

The net proposed appears to require rather larger spreading forces than would normally be available from otter boards matched to towing power (Figures 25, 27). There is thus a choice of accepting an inadequate spread (by using a too small board) or a slightly reduced towing speed. In this case, it is probably best to accept a reduced speed.

If gross incompatibility occurred, it would be necessary to investigate the possibility of using a more efficient type of otter board or of reducing the size of the net.

CHAPTER 4

OTTER BOARD DESIGN, CONSTRUCTION AND PERFORMANCE

Otter boards are manufactured to a limited number of basic designs (with many minor differences) in all parts of the world and it would not be possible in this text to cover all the variations of even the main popular types that are discussed here. Otter boards are also manufactured in a range of sizes to suit all sizes of trawls, including those used in shallow bays and inlets, up to the large nets used by the deep-sea trawlers. The traditional design of otter boards has evolved over a long period by trial and error; advanced technology is only now playing a part in producing new designs with increased hydrodynamic efficiency. Perhaps one of the main reasons for the slow progress in design and manufacture of more efficient otter board types is that the conventional rectangular flat board is a relatively inexpensive item of the total fishing unit. Another hindrance to innovation is that any new type of otter board that may be produced by a fresh technological approach might require changes in fishing procedures not compatible with existing ships and gear. Any advantage in a new type of otter board must outweigh all cost increases associated with the change, not only for materials but also for any associated boat work.

The main materials used in otter board manufacture — steel and wood — have not changed since their introduction at the turn of the century. Although other materials such as fibreglass reinforced plastic (GRP), laminated wood, aluminium, glass beads and polystyrene (used as buoyancy materials) have been used so far none of the boards incorporating them is in common use.

Many of the following remarks on the background, construction, economy, efficiency, handling, materials, advantages and limitations are common to more than one otter board type or are covered elsewhere in this manual, but for completeness of the descriptive list and avoidance of extensive cross-referencing are repeated for each board when relevant. Full engineering drawings are included as examples.

4.1 Rectangular flat

The rectangular flat otter board was first introduced in the late 19th century and probably is still the most popular board in use for bottom

trawling. It is claimed that otter boards were first used on small nets by yachtsmen in the sea lochs of western Scotland and that a Mr. Scott of Granton was the first to design a commercial trawl for use with otter boards in 1894. By the end of the century, this type of gear had been adopted by all the steam trawlers. Originally, the otter boards were attached directly to the wings of the net, but around 1920 a system was introduced by Vigneron Dahl in which the otter boards are attached to the wings by sweep lines (bridles) and spreading wires (legs). This system increased the catch rate (using the same net) through the herding effect of the connecting lines and otter boards.

A typical rectangular flat otter board (Figure 29) consists of a steel frame, with various steel strengthening struts enclosing a fabricated wooden plate. The basic frame is constructed from U channels of varying weights, depending upon otter board size.

The U channel is bent into the required shape (main frame) after which the sole plate is bent to shape and welded (sometimes bolted) to the base of the main frame; this member serves a dual purpose: as a strengthening member to take loads imposed by ground contact and as a weight to control the centre of gravity (C of G) position. Side plates are then cut to fit either side of the main frame over the lower part of the board and welded on. The object of these plates is to prevent the planks fitted between the plates from being damaged during bottom contact or surface handling.

At this stage, the planks and steel strips are fitted into the main frame; the strips are bent up at each end and are bolted through the main frame so that when each plank is fitted, the ends of the main frame can be pulled in to make the board into a rigid structure. The planks are fitted carefully to the frame to ensure maximum strength and they are often slightly thicker than the inside size of the channel so that the planks fit tightly into the U channel at all points.

Once the planks are fitted, the end plates are made to fit round the main frame as shown and cut to facilitate welding to the main frame and side plates. The planks and end plates are then bolted together and back strengthening channels (used to transmit loads throughout the board) are fitted in position corresponding to the location of the triangle warp brackets and backstrop fixtures.

Wherever bolts are used, they should preferably be of the round-headed (coach bolt) type to reduce the danger of damage to other parts of the gear or ship by snagging. The bolted construction of otter boards has caused maintenance problems as vibration eventually causes the bolts to work loose after a period in operation. This has the effect of enlarging the holes in the planks causing a localized weak point which can lead to the eventual fracture of a plank. This problem has largely been overcome by tack-

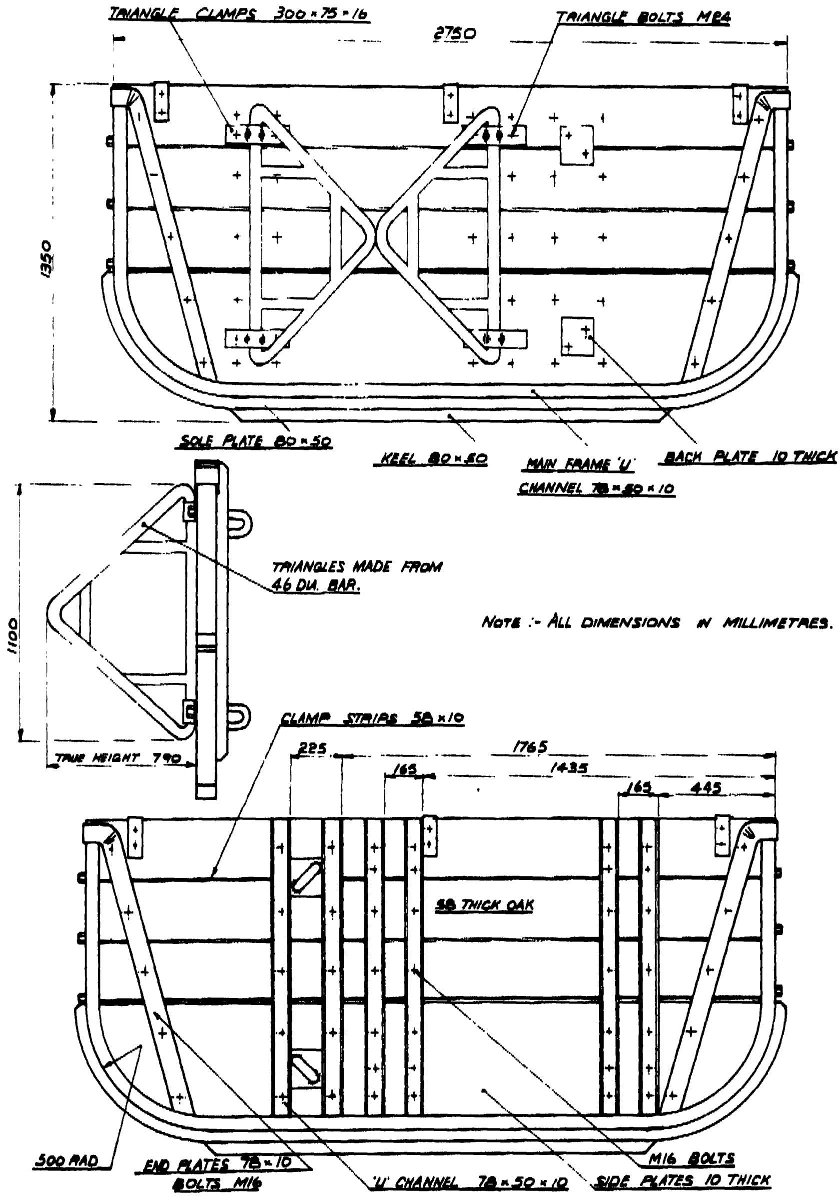


FIGURE 29. — Construction drawing of a typical rectangular flat otter board of 3.7 m².

welding nuts and bolts together on assembly, although modern locking compounds are available that probably could also serve.

The design of the otter board shown in Figure 29 is only one example. Depending on the type of ground to be fished, parts may be added or removed as desired. The board shown would be suitable for rough ground, although front and aft end plates could be added if the ground is expected to be very rough. End plates are made to fit next to the planking and are held by the clamping strip bolts and welded to the main frame. If a board is not to be used on rough ground, in certain circumstances the sole plate may be reduced in thickness or the keel plate left off. In some cases, the sole and keel plates are replaced by skids which give a little weight to the bottom of the board but, more important, provide a wide surface area for the board to run over soft muddy bottoms without digging in. However, when trawling is predominantly on rough grounds, it is becoming common practice to construct the sole plate in several separate sections or to add special strengthening sections which are easily replaceable, even at sea. It is usual to protect the top of the board by the attachment of a length of steel strip along the top edge.

For the larger range of flat otter boards, the main frame is generally made from steel U channel, as are the vertical strengthening members, although it is possible to fabricate a main frame by assembling the planks into the size of board required and then attaching a strip of plate (say 10 mm thick for a 4 m^2 board) around the outside edge. Edging pieces are then made to fit around either side of the edge and bolted into position, after which the three pieces are welded together to produce quite a sturdy main frame.

The wood used in the manufacture of the larger sizes of board (2 m^2 and larger) is generally a hardwood (oak, elm, beech), while for smaller boards it is quite common to use softwood such as spruce or pine. Most of the metal parts of the board are welded together by continuous welding, except for the vertical strengthening plates which generally are only bolted to the planks and not attached to the main frame.

The rectangular flat otter board has always been regarded as a fairly inexpensive structure to produce through its design and the fact that suitable materials were generally available. However, the design does not lend itself to modern quantity production — a limitation that may become more important in the future.

The board has a robust construction, can be used on most kinds of ground, is easy to use, but costs of maintenance are becoming higher, especially for small companies.

Interchangeability can be provided (as for the Vee type otter board) through careful design of the vertical iron strengthening members which carry the bracket for the warp and the rings for the backstrops. However,

to obtain proper interchangeability between port and starboard operation the lower edge and the shoe plate must be symmetrical.

The rectangular flat otter board is not very efficient hydrodynamically, as a great deal of turbulence occurs in the water behind the board which increases the drag and reduces the spreading force. In steady towing conditions, it leans slightly outward and the water flowing over the face tends to exert an extra downward pressure, which increases the tendency for the board to dig into the seabed. The board tends to dig in because of the straight lower edge and the large angle of attack, of about 40 degrees, at which the boards operate with conventional wire attachment points. Alternative positions for fixing the rings for the attachment of the backstrops are sometimes provided to enable easy alterations of the angle of attack. This will be increased by shifting the rings forward. If the warp brackets are partly or completely made of chain, another easy means for adjusting the angle of attack is provided. If important changes are made in the attachment points of the warp and/or the backstrops to endeavour to reduce the angle of attack and improve performance, the result is usually a certain decrease in stability. The high contact pressure between the board and the seabed tends to generate shock loads within the board which can lead to total destruction when working on very hard ground.

The flat board is one of the simplest to handle. They hang neatly in the gallows or against the stern and lend themselves to easy deck storage taking up only a minimum of space. Providing they are manufactured with rounded nuts, bolts, etc., they cause little trouble (e.g., snagging of the net or ropes) during fishing operations.

The main limitation of the flat rectangular otter board is that it does not run easily over very rough ground and consequently tends to have a limited life. When used for prolonged periods on adverse seabed conditions, it is not uncommon for a trawler to destroy a pair of boards in 14 days. In practice, however, total life expectation is much in excess of that time; indeed, some trawlers have used boards for two years before they required replacement.

4.2 Rectangular flat, wide keeled

This otter board is a variant of the standard rectangular type. It is a light and simply constructed board widely used, particularly for shrimp trawling (Figure 30).

The main board is assembled by laying and joining the planks with nails after which the planks are drilled and bolted together to provide a secure structure. The wide shoe is then bent to fit the radius at the front of the board

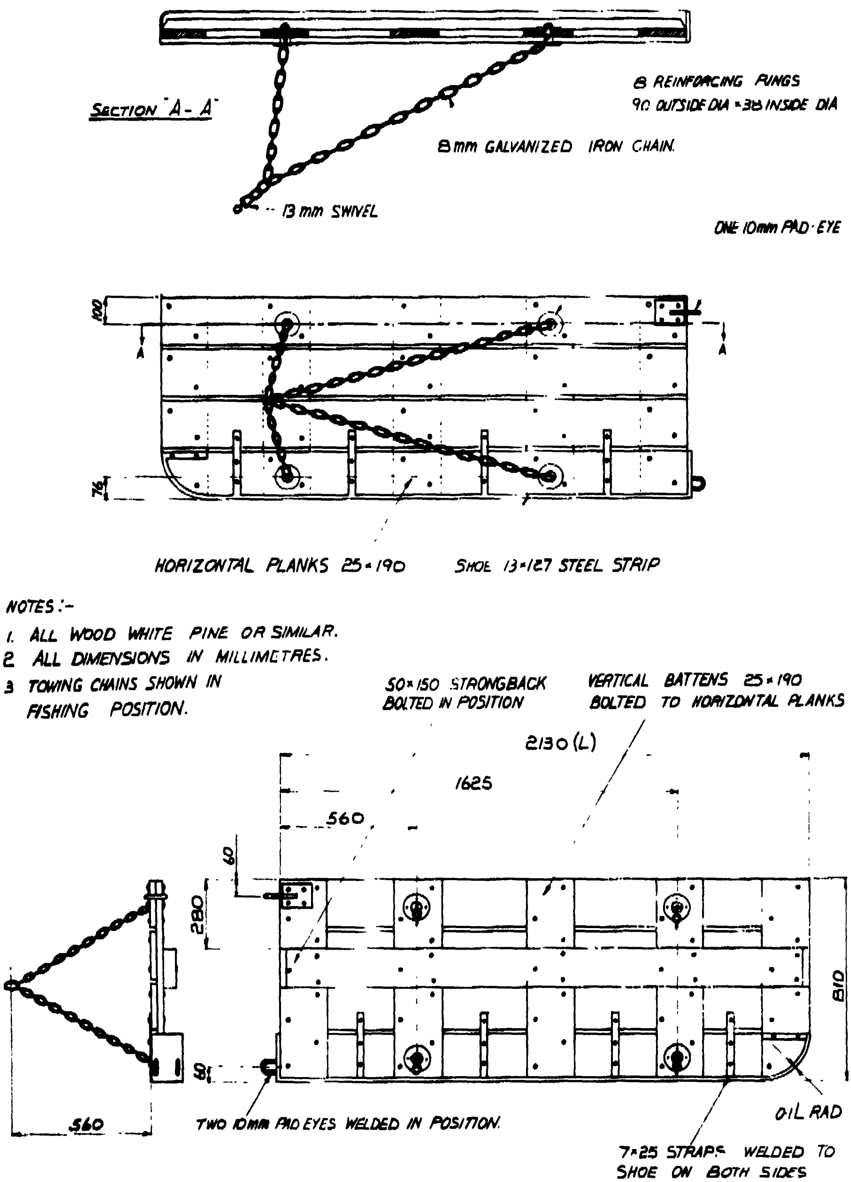


FIGURE 30. — Construction drawing of a rectangular flat otter board, wide-keeled type for shrimp trawling, of 1.7 m².

and bent up at the heel. The straps are welded to the shoe, which is bolted to the main board. The holes for the towing chains are then drilled and chains are fitted by passing them through the holes, using a simple retaining system. To complete the board, the backstrop attachment points are fixed in the form of pad-eyes.

The main material used is yellow pine or other softwood. The few attachments are made from steel plate and rod and galvanized steel chains.

There is little doubt that this is one of the cheapest boards in use and can be made with the simplest of tools. The welding involved is minimal and the main skill required is in carpentry. This board is suitable for use in the shrimp fishing industry, in which most trawling is carried out on clean, soft ground. The wide sole plates counteract digging into the bottom.

The hydrodynamics of this board are similar to or slightly worse than any typical flat otter board. It is sometimes claimed that the horizontal slots left between the planks positively influence the turbulence behind the board, but this is considered unlikely.

Like other flat otter boards it is easy to handle, particularly because it is very light. The towing chain attachment system (warp bracket) lends itself to easy adjustment of the angle of attack and the heel by shifting the towing point through lengthening or shortening of the appropriate chains. Usually these boards are manufactured with chains longer than required so that the lengths can be set according to individual preferences. The chains are usually adjusted with the forward top strand set one link longer than the forward bottom strand and the top rear strand set two links longer than the bottom rear strand. The forward chains are generally one half to two thirds the length of the rear chains.

This chain setting causes the boards to lean slightly outward, giving some downward sheer which ensures good bottom contact. They also tend to run slightly nose down.

The main limitation of these boards, apart from their rather low hydrodynamic efficiency, is that they are unsuited for rough ground.

4.3 Rectangular cambered (low aspect ratio)

The cambered otter boards of the type shown in Figure 31 were developed through a scientific study of otter board design and manufacture. They were produced in the early 1960s by a British company which had also been concerned with the hydrodynamic theory of various shapes of otter board and the conduct of tank tests on model boards to determine water forces acting on them. Although these boards have been available for

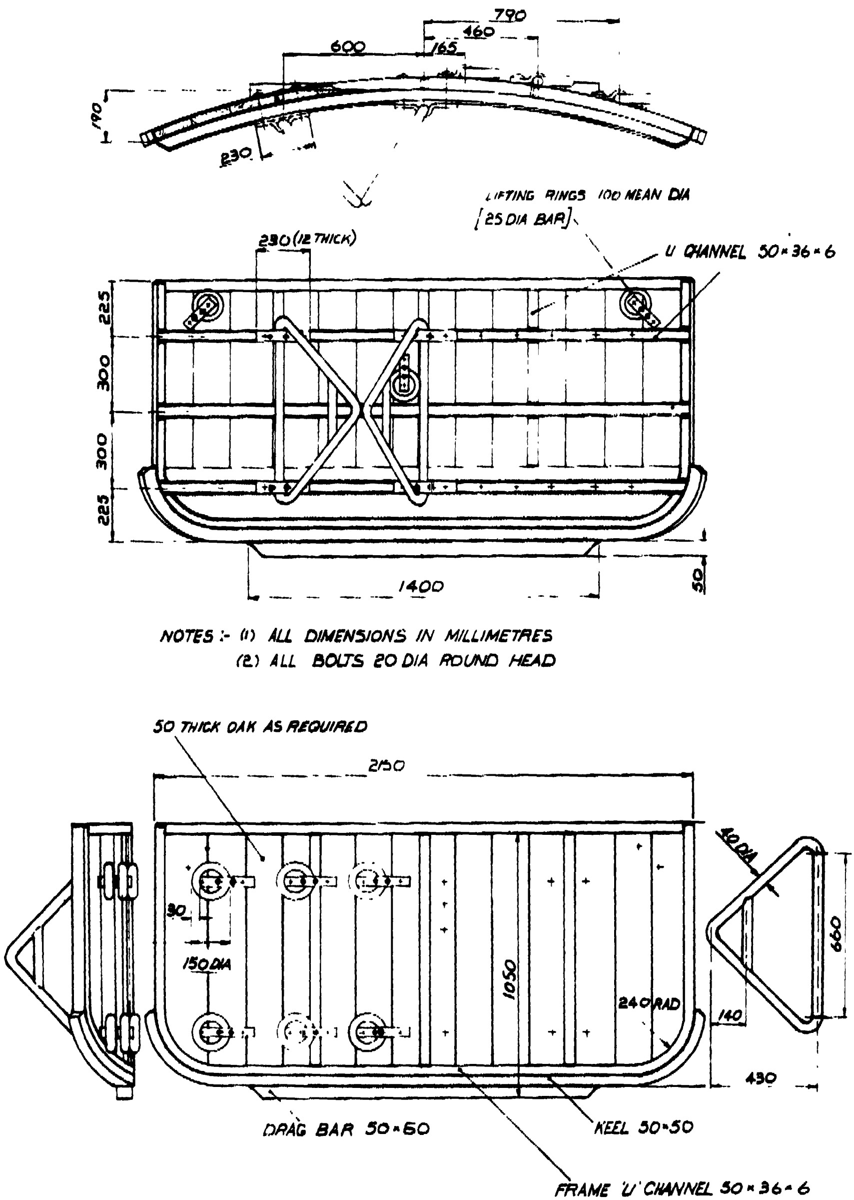


FIGURE 31. — Construction drawing of a rectangular cambered otter board of low aspect ratio (1:2) of 2.2 m².

over ten years, very few are in commercial use and at present it appears that the polyvalent board (see 4.5), which is a combination of a cambered board and an oval board, may well become one of the main beneficiaries of the hydrodynamic advantage of using camber for demersal otter boards.

The outstanding physical feature of cambered otter boards — apart from camber — is weight, particularly in the larger sizes, which have a metal plate overall on the back face. On small cambered otter boards like the example shown in Figure 31, the back plate is omitted. The main peculiarity in structural design is the lay of the planks. They are vertically mounted in the frame to allow the camber and, unlike the flat boards, require horizontal ribs to run the length of the board. The main frame, manufactured from U channel, is first bent into shape and then rolled to give the required rise of camber of 9 percent of the total length of the board (design with camber of 6 and 12 percent have also been tried, but the intermediate value appears best). The keel plate is then bent to shape and welded onto the main frame. The straight square-sectioned steel drag bar is then welded across the underside of the keel. This acts as a structural member, giving the base of the frame extra strength as well as providing a straight edge for the otter board to run on. It also provides a counter to much of the wear and helps to lower the position of the centre of gravity.

The planks are fitted into the frame and, as they are usually the same thickness as the outside size of the U channel, it is ensured that they fit at all points. The planks are interspaced with vertical U channels which transect the attachment points for the towing brackets and backstrops to give additional strength in these areas. The top section of the main frame is then bent into shape and welded at the top ends of all vertical members to complete the basic structure. Longitudinal ribs and front chafing plate are rolled to fit along the inside of the board and are bolted into position, after which they are welded to the various metal members (main frame and vertical strengthening ribs). Finally, the towing brackets, backstrop rings and lifting rings are bolted on with the heads of roundhead bolts against the back face.

The normal materials for this type of otter board are steel channel and hardwood for the planking. Because of the vertical lie of the planks, it is inadvisable to use softwood in these boards, especially if they are to be used on hard ground. It would probably be preferable to make this type of board in all-steel structure, but so far this has only been done on an experimental scale.

The cambered otter board is more expensive to produce than the rectangular flat, but the cost can be offset to a certain extent by the better hydrodynamic efficiency and durability. The greater efficiency can be used either

to produce a greater spread at lower towing power, or the same spread as with a flat board but achieved with a board of smaller size, or to tow at greater speed.

Efficiency in terms of spreading force is gained by the water flow following the curved surface round the rear of the board and thus being less turbulent. These cambered boards operate at a smaller angle of attack (i.e., of about 30 degrees), which leads to lower towing resistance and may also reduce the tendency of the board to dig into soft ground.

The cambered board is quite easily used on common trawlers. To obtain optimum efficiency, care must be taken to ensure correct positioning of the take-off points for warp and bridles because the proper rig is also important for shooting and hauling. It has been found that these boards are better shot at high vessel speeds; this is more easily executed on a stern trawler than a side trawler. The lifting rings shown are only an indication of position and they should be attached in the position that will let the board hang neatly in the gallows or against the stern.

A particular disadvantage of these otter boards is their reluctance to right themselves after falling flat, which may happen when taking sharp turns. This problem is greatly reduced by ensuring the correct warp and bridle attachment points.

4.4 Oval flat slotted

Oval flat slotted otter boards (first introduced around 1950) are used by the fleets of the U.S.S.R. almost to the exclusion of other types. They are also commonly seen on other northern European trawlers and seem to be increasingly adopted by other developed trawl fisheries (Figure 32).

The main area of the board is made in two parts, a forward and an aft section, usually in hardwood, shaped to provide a slot at the required position between the two sections. The shape of the slot varies from one design to another. The wooden ends which form the vertical sides of the slot may be finished square or complementarily chamfered or otherwise streamlined. There is little firm evidence to suggest that the slot slope characteristic is of any great importance.

During construction, some temporary clamping for holding the planks together may be necessary. The wood sections are connected to the main top and base plates of the keel and top sections respectively, after which the remainder of the top compartment is completed in position. The top compartment can be made as an all-steel structure, free-flooding or timber-filled. The body of the steel section above the keel is made to fit against its top plate. The keel is usually given a concrete core to increase operational stability.

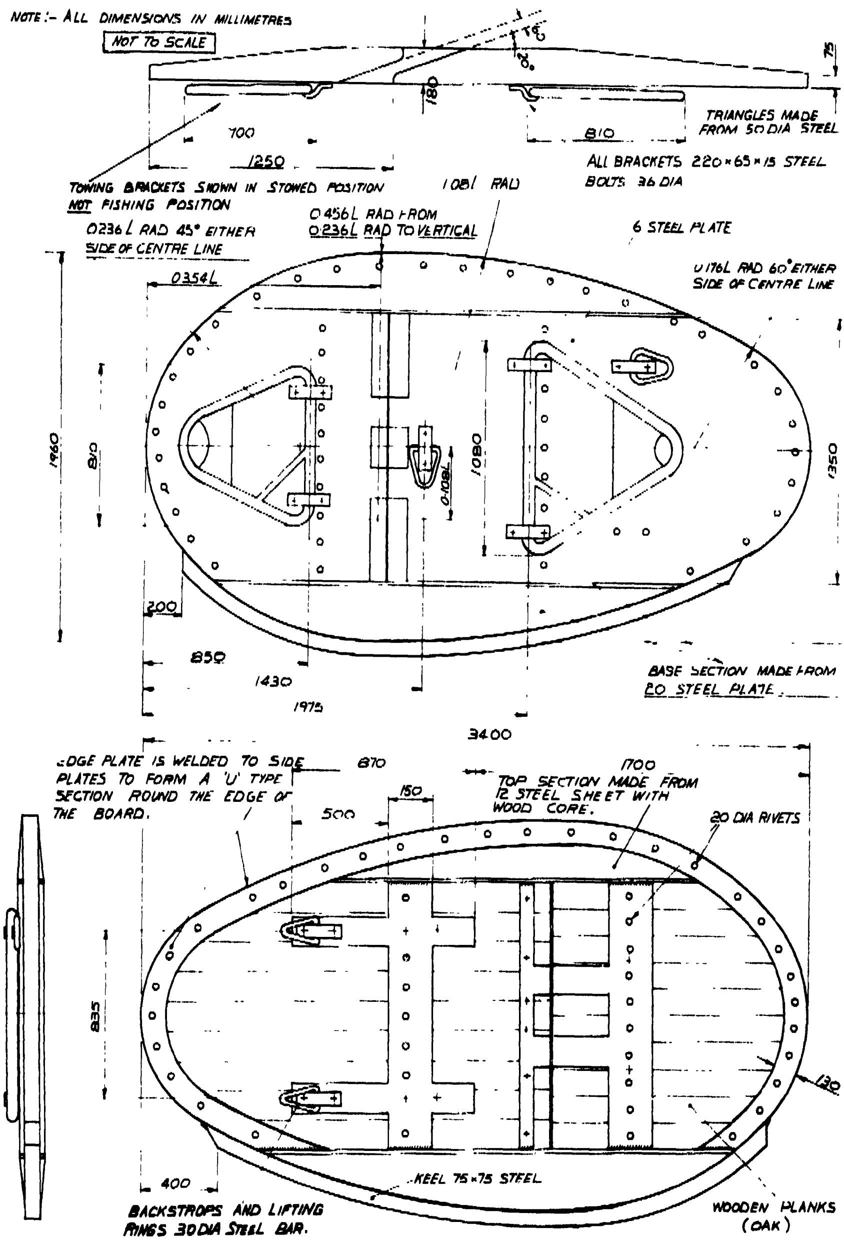


FIGURE 32. — Construction drawing of an oval flat otter board with one slot, about 5.2 m².

A steel plate is bolted to the front face of the board to give the planking complete protection at the front and steel crosspieces are bolted at suitable positions on the back face of the board as well as the back peripheral edge plate. These boards are often banded with steel, the band being welded to the front plate and back peripheral plate. The triangle brackets, backstrop rings, lifting rings, etc., complete the board construction.

The large version of this board (Figure 32) is rather expensive to manufacture, but as its shape lends itself to easy progress on rough ground, and with the use of "defensive" design, the board has a long life expectancy. This partly offsets the high initial cost. Maintenance costs are also quite high, especially when lower grade materials or workmanship are used. It must be remembered that these boards are specifically designed for use on rough ground and, therefore, a strong, well-protected structure cannot be omitted. Removable sole plates in several pieces can be used to facilitate maintenance.

The oval flat board has slightly better hydrodynamic properties than the rectangular flat board. The rounded lower edge, which affects spreading performance adversely, is beneficial to overall performance on very uneven and hard ground because it reduces ground friction and mechanical stress. On a solid rock surface, the ground contact forces for the two flat otter board types are not significantly different because for both there will be only a small area of contact between the keel and the ground. On soft sandy or muddy ground, the oval board will not dig in to any great extent. The vertical slot opening is intended to increase the hydrodynamic efficiency of the board by reducing the turbulence round the back surface, as does the curvature of a cambered board.

Rectangular and oval flat boards are very similar in handling properties, shooting, storing and stability in operation. Both can be manufactured with very clean lines which remove any risk of damage to associated equipment.

The main limitation of the oval flat board is its lower spreading force on clean ground as compared to a cambered board of the same area. On such grounds, the oval board will also have less spreading force than a conventional rectangular flat board because of less ploughing, and for the same reason the oval board has less bottom resistance so that its efficiency (spread to drag ratio) is higher. The oval flat board is not suitable for midwater trawling and, therefore, a pair of midwater otter boards must be carried as well if midwater trawling is contemplated.

4.5 Oval cambered slotted (polyvalent)

Polyvalent otter boards are one of the most recent types to appear on the fishing scene. They were introduced in France by the designer and

manufacturer Jean Morgere of St. Malo. These otter boards are a combination of the oval board and the cambered board, giving the increased spreading efficiency of the cambered type and the ability to traverse hard ground.

A great deal of interest is being shown in this type of board and it is possible that it could become the first really commercially successful and hydrodynamically efficient bottom-trawling otter board apart from the high-aspect-ratio Japanese cambered board.

An example of a modern design made under patent, the polyvalent otter board calls for a considerable degree of engineering experience to manufacture properly.

The structure is all steel and requires a wide range of steel plate and sections. Figure 33 shows typical construction details. A system of manufacture could be as follows: A U channel is manufactured from 6 mm sheet steel to form the top section, which is then made into a box section by welding on a steel strip the width of the U-channel along the top. A section of 25 mm gauge steel plate is then cut to form a strengthener and backstrop take-off point, which is welded to the back end of the box, and the box section is completed by drilling through the base of the section a series of holes about 20 mm in diameter equispaced along its length. A similar U section is then built for the keel section using 20 mm steel plate and including a number of vertical ribs inserted into the structure, after which the keel plate of 100 × 55 mm steel is attached along the base of the section, either by welding or riveting.

As it is not intended to produce a watertight section, the keel could be attached in two or three parts with clearance spaces of 10 mm or more between the sections to allow unrestricted water flow. A plate, similar to the one attached to the top section, is welded to the keel section for attachment of backstrops (care should be taken to ensure that the positions of these two plates are identical). Two lengths of screwed rod are fitted to the keel section, to secure the weights used to adjust trim.

The main back plate would then be manufactured from 12 mm steel plate which is cut to the required shape and rolled to obtain a 6 percent camber. This main plate is then welded to the two existing box structures to achieve a section profile as seen in the end view shown in Figure 33. The ends of the centre section are then finished by welding on lengths of 30 mm diameter rod along the edge to increase the strength of the board. The bottom part of each end is further strengthened by the attachment of strengthening plates 11 mm thick welded into position. A slot can then be cut out of the main plate in the position shown and edged with a 30 mm diameter bar welded to the outside of the board for the forward edge of the slot and to the inside of the board for the rear edge of the slot,

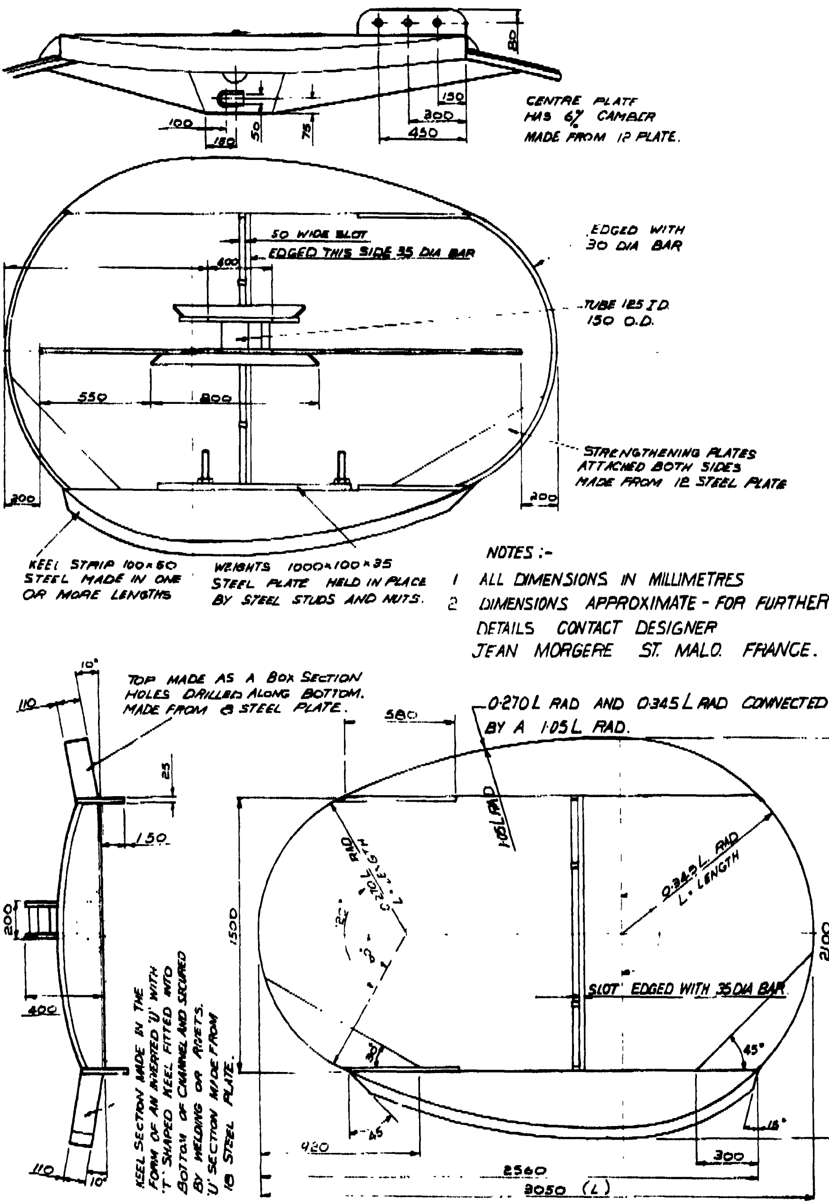


Figure 33. — Construction drawing of an oval cambered otter board with one slot (polyvalent), of about 4.9 m².

so generating a suitable angle for water flow through the slot. Two strengthening pieces of 30 mm diameter rod can be welded across the slot to maintain longitudinal strength. The centre rib containing the lowing point and various attachment and lifting points can be made from 25 mm plate and continuously welded to the backplate. An additional towing point above the centre line is provided for midwater trawling.

The polyvalent board is relatively expensive, largely because of the complexity of producing both oval profile and camber. The system of manufacturing could lend itself to batch production of various sections, but there is still a considerable amount of welding, bending and profile cutting to be carried out which is bound to keep the cost of this board higher than that of the conventional flat otter board.

Since these boards are suitable for use on the bottom or in midwater, they can cover all requirements of versatile trawling. Of course, they are not as efficient in midwater as the high aspect ratio cambered boards (e.g., the Süberkrüb type), although they are hydrodynamically more efficient than an oval flat board of the same surface area. Furthermore, they are rather heavy for midwater trawling close to the surface. Considerable instability has been observed, especially over rough ground, possibly due to intermittent ground contact. Changing the attachment points appears to reduce this, but experience of what and how much adjustment is needed varies from skipper to skipper; in short, not enough is known yet.

The polyvalent boards are probably the easiest of all otter boards to handle on board, owing to their lack of triangles and other appendages. This also reduces the tendency for other parts of the gear to become entangled with the board.

Although these boards are basically suitable for both bottom and midwater trawling, in practice skippers tend to carry additional special midwater otter boards of the Süberkrüb type and to use the polyvalent boards exclusively for demersal trawling. This, of course, reduces some of the justification for the higher capital cost, but durability and hydrodynamic efficiency cannot be denied.

4.6 Vee type

The Vee type otter board was developed during the 1950s and, naturally, since then has been further improved and modified. So far, these boards are mainly used by inshore fishermen who appreciate their good performance on very hard and irregular ground.

The Vee form of otter board is built to a simple structure made entirely in mild steel — thick wall tube, solid round bar and plate. The typical design of a Vee board shown in Figure 34 is constructed as follows

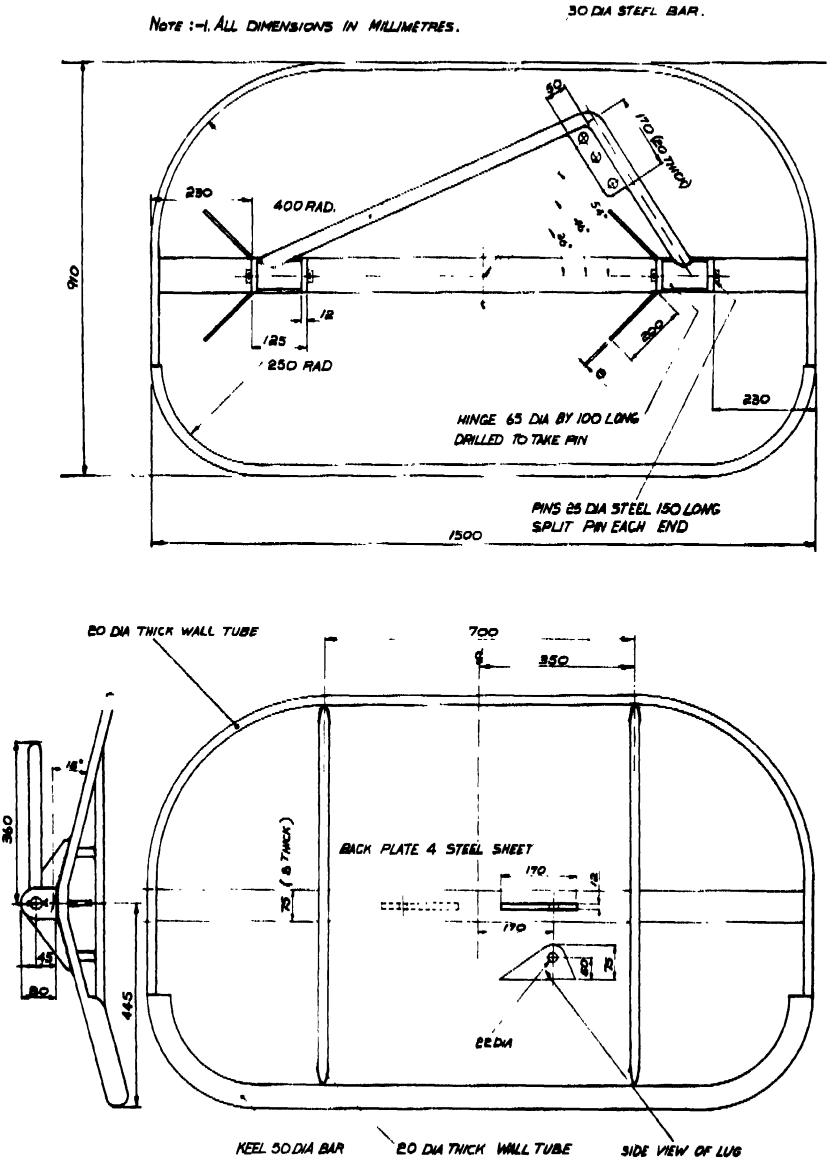


FIGURE 34. — Construction drawing of a rectangular Vee type otter board of about 1.3 m^2.

The keel section of the main frame is made of solid steel bar bent into the required shape. Thick walled steel tube is bent to shape and the ends butt-welded to the ends of the keel to complete the main frame. The frame is then bent in accordance with the geometry shown in the end elevation and then covered with a mild steel sheet of light gauge and welded. This cover may be either in three parts (top, bottom and centre plate) which are cut to fit into the frame and then continuously welded, or alternatively as one sheet on the inside of the frame. The latter has the advantage that it produces a board with as smooth an inner surface as possible. The towing bracket is then attached, taking care to arrange for it to be interchangeable to allow the board to be fished on either side. Two back tie rods are then manufactured out of thick walled tube similar to that used for the top frame and welded onto the back plate as shown.

Care should be taken to ensure that the metal used in this all-steel construction is not brittle, as larger boards of this type have shown tendencies to cracks at the corners. On some of the larger Vee boards it is common practice to alter the design of the vertical tie rods and make them from plate filling in the complete Vee of the door.

The Vee board is relatively inexpensive to manufacture and its main advantages are its ability to fish on hard ground and to retain a long working life. The interchangeability of the towing bracket is an important factor in favour of the Vee board, because spare boards can be fitted either way around to make either a port or starboard otter board. This ability to use the boards on either side also means that the keels can be worn evenly by changing the boards over from time to time and thus effectively prolonging the period between servicing.

The disadvantage of the Vee board is its inferior spreading force, even as compared to the rectangular flat board; but as the catch rates are often high on very hard grounds which may not be accessible to rectangular flat boards, this shortcoming may partly be outweighed.

The Vee board is easy to handle and simple to shoot, haul and stow. They require more storage space than flat otter boards but, since only one spare is necessary, storage is not usually a serious problem.

In their progress through the water, Vee boards fluctuate about and are easily diverted by obstacles. Because of this lack of rigidity they are actually stable insofar as they ride over such obstacles and quickly fluctuate back to a suitable angle. This special characteristic also has an advantage in terms of manœuvrability, that is, even with sharp changes in direction of tow, special precautions of hauling up on one warp, etc. are not usually needed. This is most desirable when trawling on bad ground and where large local obstructions have to be avoided.

It should be noted that the Vee boards are generally heavier in weight

than the other types of demersal otter boards; this is useful to counteract the specific operational upward sheer component.

4.7 Rectangular, special design (diverting depressor)

The diverting depressor is a recent addition to the otter board family. It originated in Hong Kong and is produced under patent on a world scale by Tong Lye & Company Ltd. The spreading part of the diverter has a slight positive buoyancy due to the horizontal buoyancy chamber, while the complete diverter assembly has a negative buoyancy obtained largely by the attachment of two suspended spherical steel balls (Figure 35). These special otter boards are now being used in many parts of the world, but as yet have not seriously challenged the more conventional types.

Like the polyvalent otter board, the diverting depressor is manufactured under patents and the construction requires a fair range of engineering equipment and expertise. The following description of a possible method of construction gives an idea of the work involved.

The board is symmetrical about its horizontal axis and the main buoyancy chamber is made from two pieces of sheet steel formed into shape. The two halves, the steel wings and the preformed cones are welded together and four small triangular pieces of plate are then cut and welded to fit the remaining spaces between the cones and the main chamber, thus completing the main assembly. The quality of all this welding has to be very high. Three vertical webs are then welded to the structure. The webs are manufactured from four individual sections, the fabrication of which incorporates towing points. The various webs are welded in position around the outside edges of the wings and along the length of the cylindrical section. Fins are welded to the tail and a strengthening ring welded to the fins after which the various holes required for accessories are drilled. Two cradles are made from steel strip and fitted with shafts to accept the steel balls. It is then possible to complete the assembly, using the chains and spacing rod.

Construction is all steel with polyurethane rigid foam or similar material being used to fill the buoyancy tank. The foam has the advantage of giving some added strength, but it does of course add slightly to weight and thus reduces the buoyancy of the main tank.

Diverting depressors are designed for use on all kinds of ground and, therefore, despite a high initial cost compared with a conventional flat otter board, may be justified. An increase in catch accruing from the ability to fish on harder ground and an increase in board life due to the reduced ground contact (only the robust steel balls are in contact) could

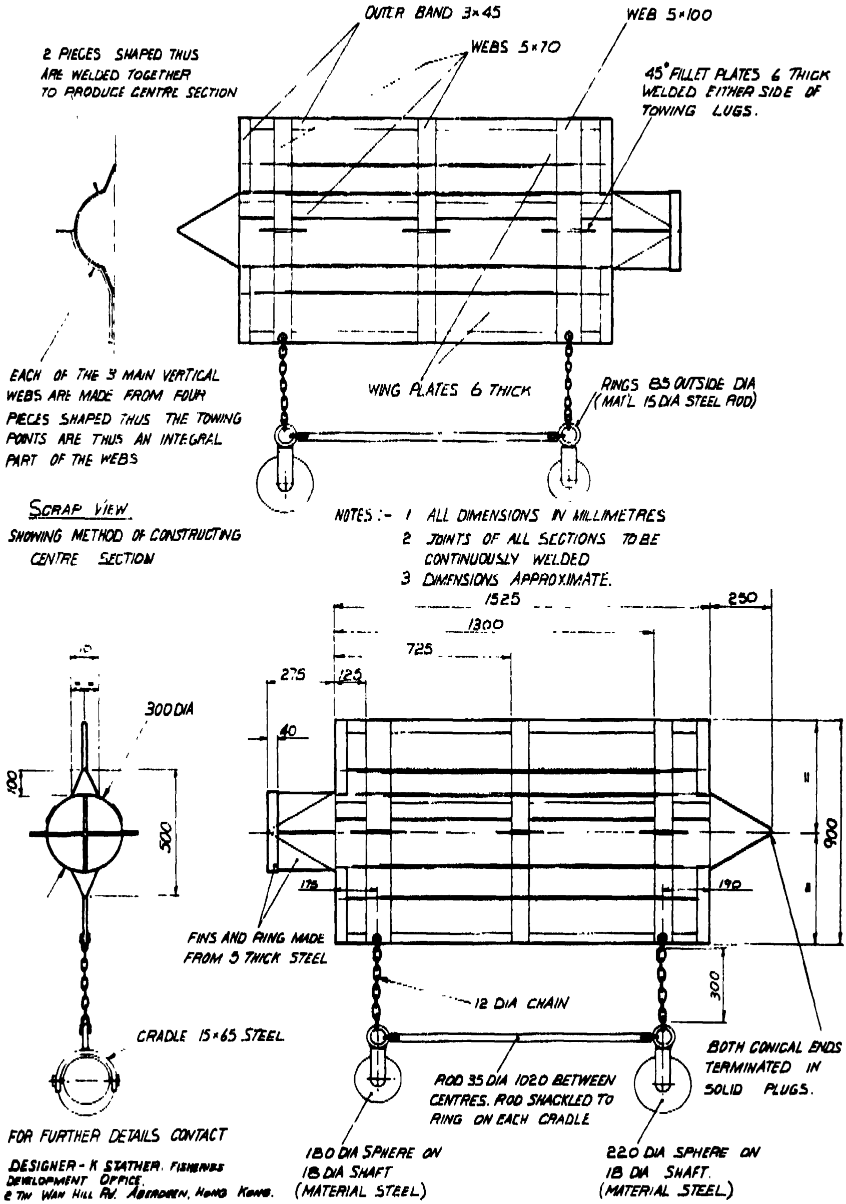


FIGURE 35. — Construction drawing of a rectangular otter board, special design (diverting depressor), of about 1.4 m².

offset the cost. As with the Vee type otter board, the diverting depressors are interchangeable and can be fished on either side. This represents a saving in cost and deck storage space if only one spare board is carried. In some cases, a slight additional initial expense may be involved in the various cleats, protection plates and other fittings usually required to cater for easy handling of the boards and spheres at the gallows.

The diverting depressor is similar in hydrodynamic spreading efficiency to a flat rectangular otter board of the same surface area, but with the advantage that the spreading force is not affected to the same extent by ground interference. The board has the ability to run well over hard ground and can also retain a stable upright position when being used in midwater. Its hydrodynamic efficiency is, however, inferior to cambered boards. Therefore, as with other boards that can be used for bottom and midwater trawling, it may be necessary to carry an extra pair of high aspect ratio cambered otter boards for midwater trawling.

Apart from the necessity of devising a system of dealing with the steel balls when the boards are on the boat, there is no generally reported problem in handling them. In towing, they actually give the skipper the ability to manœuvre at will and even stop his boat without risk of fouling. This is a rare feature in an otter board, and is made possible by the buoyancy keeping the boards in the vertical position when stopped and until trawling is resumed. Other boards, especially the cambered type, will not right themselves after falling and have to be partly hauled and reshot.

The depressors do have a depth limitation imposed by the pressure resistance of the buoyancy tank which has to be taken into account.

4.8 Rectangular cambered (high aspect ratio Süberkrüb type)

This type of otter board was developed in the 1930s originally for bottom trawling but, in spite of highly promising trial results, was not readily accepted by the commercial fishery, probably because of operational implications. Due to its hydrodynamic superiority over all other types of otter boards, this type, commonly known as the Süberkrüb otter board (after its designer), is at present most popular for one-boat midwater trawling (Figure 36). It has a high aspect ratio of approximately 2:1, that is, the height is about twice the length. The amount of camber is related to the width of the board; the curvature is the section of a circle the radius of which is equal to the length.

The all-steel Süberkrüb otter board is relatively simple to manufacture — provided that some kind of roller is available for forming the main plate. When producing these boards, the initial step is to roll the main

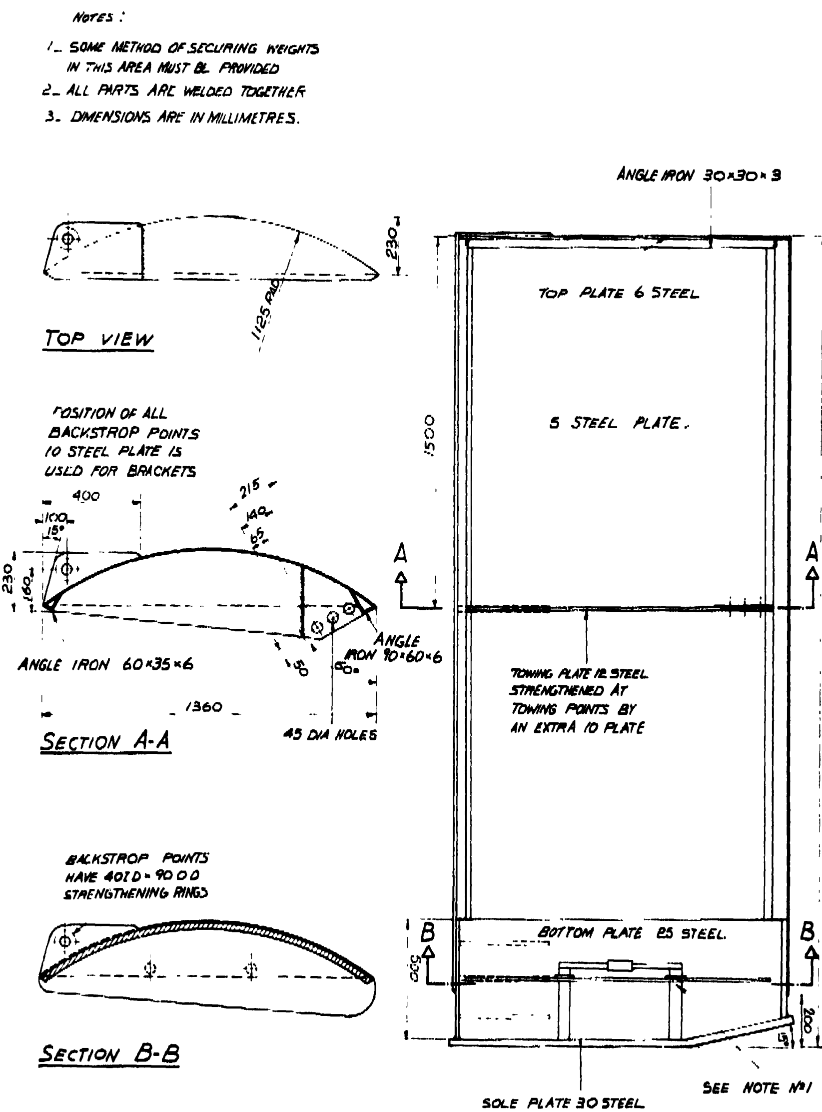


FIGURE 36. — Construction drawing of a rectangular cambered otter board, high aspect ratio (Süberkrüb), of about 4.4 m², for midwater trawling.

plate to the given camber and then roll the bottom (ballast) plate to fit inside this main plate. The two plates are welded together, after which the

sole plate, made of heavy gauge material, is cut to the required shape and bent to give a toe rake of about 15 degrees. The foot of the bottom plate is then cut to accept the sole plate and they are welded together.

Angle irons can then be welded to the leading and trailing edges of the board, after which the top plate is cut and fitted into position with a cross rib of angle iron welded along the outside edge. The towing plate, which has the function of the bracket, is cut and welded in position. The areas immediately around the towing points are strengthened by the addition of extra plate washers. The backstrop brackets are made from plate and strengthened by similar washer rings. The only remaining task is to make some arrangement to enable fitting of such additional ballast weights as may be needed to adjust the trim for particular fishing conditions.

Süberkrüb boards are mainly used for midwater trawling. Provided they are not abused, especially in hauling in to the gallows, they will last for many fishing trips. Comparatively inexpensive and durable, the Süberkrüb boards are unlikely to be matched for fast economy in pelagic fishing. The present methods of control by warp length and towing speed changes are fairly satisfactory for vertical control.

The Süberkrüb board creates little or no turbulence. It can be rigged to provide an upward or downward sheer component or to act only in a horizontal direction. This can be effected by shifting vertically either the point of attachment of the warp or of the lower backstrop. Upward shift of these points will increase the upward sheer component. To this end, it is usually provided with two bracket plates for the warp and three or more for the lower backstrop. Turbulence is avoided by the camber and the high aspect ratio improves the sheer to drag ratio. This efficiency, which is marked by a very low drag, makes the board a superior spreading device. Because of the large size of midwater trawls, these boards are made in sizes up to 5×2.5 m or about 12 m^2. It is anticipated that even larger versions will come into use in the future.

No special handling problems are associated with these boards, especially when operating from stern trawlers. Understandably, when very large boards are used, care must be taken to ensure that they are secured against the ship by attachments suitably positioned to permit easy and quick operation. These boards are now normally made entirely from steel, which is easy to work and strong enough to take considerable loading; and although experimental boards in other materials have been tried, there seems to be no immediate advantage in producing them in any other material.

There is a widespread opinion that the Süberkrüb type otter board is limited to midwater trawling to the exclusion of demersal fishing. It is particularly noteworthy that this opinion is not shared by the Japanese trawlermen who use this board extensively for bottom trawling on a wide

size range of trawlers, up to the largest, of 3 000 hp and more. This practice is in accordance with relevant extensive trawling trials mentioned earlier using the Süberkrüb design as a dual-purpose board for bottom and midwater trawling.

The main differences between the design of the Süberkrüb midwater otter board and the Japanese version for bottom trawling (Figure 37) are less camber, a larger angle of attack, a somewhat lower aspect ratio, a greater weight and combined wood/steel construction for the latter. The larger angle of attack which reduces the hydrodynamic efficiency (see Figures 11 and 14) is probably meant to reduce the risk of the board falling flat due to sharp turns or excessive warp length. The combined wood/steel construction may have historical reasons (the early Süberkrüb boards made in Europe until the mid 1950s were of this construction). Recently full profiles of sophisticated multimaterial construction with in-built flotation have been developed in Japan. The main purpose of this variation is the attempt to place the centre of gravity as far down as possible and to provide an uprighting moment to improve operational stability.

The construction of a normal version (Figure 37) is generally similar in principle to that described for the 1:2 (low aspect ratio) rectangular cambered otter board (Figure 31). Unlike the Süberkrüb midwater otter board, normal warp brackets are provided, of which the aft one may be made in chain to provide for easy adjustment and to facilitate stowing.

Special strengthening (and at the same time ballasting) is provided on the lower quarter of the board (by increasing plate thickness). A substantial shoe plate serves for easy movement over the ground. Particularly high aspect ratios (more than 2:1) which favour efficiency seem to be preferred for lower powered vessels, while for larger trawlers with 2 000 hp and over, this ratio is reduced, approaching 1.5:1. The reason for a lower aspect ratio, which implies some reduction in efficiency, is to improve stability; the displacement moment, which operates when the lower edge of an otter board comes in contact with obstacles, increases with the distance between the bottom edge (point of contact) and the main line of action of the controlling forces through the warps and backstrops.

While the combined wood/steel construction is expensive, maintenance is no worse than for other otter boards of combined construction. It is anticipated that specially strengthened all-metal versions of this board may soon be available, which would provide savings in both construction and maintenance. The handling on deck is similar to that for other cambered midwater and bottom otter boards already described. The superior hydrodynamic efficiency, and in particular the very low drag, make the high aspect ratio cambered otter boards the natural choice for low-powered trawlers. It must, however, be stressed that for proper

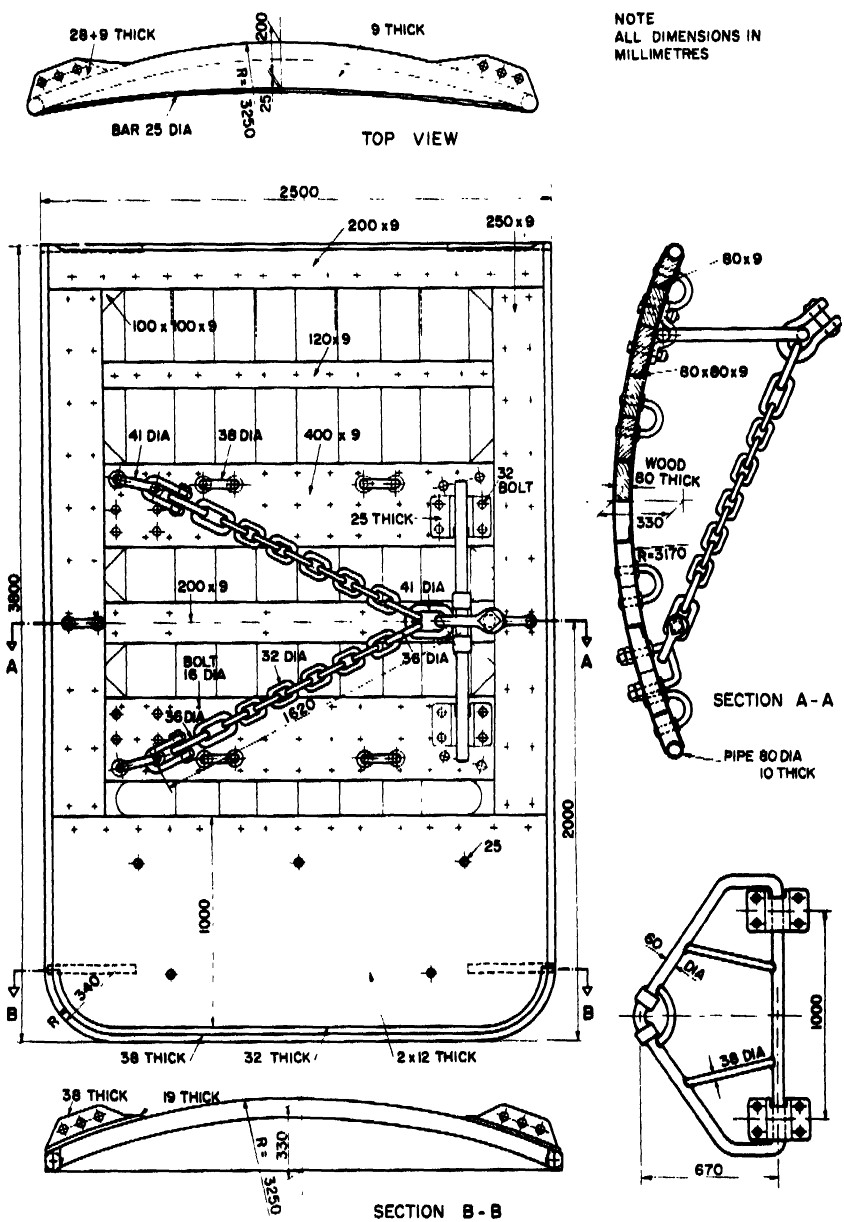


FIGURE 37. — Construction drawing of a rectangular cambered otter board, high aspect ratio (Japanese type) of about 9.5 m², for bottom trawling.

performance these boards must be carefully constructed and that efficient operation requires some additional care and skill.

Demersal trawling should be restricted, at least in the beginning, to reasonably clean and even bottom. The warp length/depth ratio must be selected so that the boards only lightly touch the bottom. Sharp turns should be avoided. The warp spread in the slip hook or at the stern gallows must be observed in order to know when a board has fallen flat. To right the board it is only necessary to haul in sufficient warp so that it comes off the ground and, after the warp spread has returned to normal, to pay out the warps again. For about the last 50 m of warps the shooting speed (of the winch) must be reduced even more than usual to ensure that the boards touch bottom in proper sheering position.

The advantages of the high aspect ratio cambered shape as the most efficient otter board profile is quite evident, particularly where towing power is at a premium, as in smaller trawlers. They therefore deserve much more attention in bottom trawling than they have so far received.

4.9 Otter board centre of gravity

The otter board's centre of gravity (C of G) and its weight are two parameters that are especially important to both designers and users. There are two main methods of determining these two parameters: one is to measure the actual board and the other is to calculate them according to the weight and distribution of the components. The latter, which would be needed for design before construction, is however considered too involved to fit in the scope of this manual. For most practical purposes of new construction, in particular the scaling up or down in size of known designs, the empirical background will be sufficient to produce a reasonably satisfactory prototype which will need little subsequent adjustment.

For practical purposes, there are actually two C of G and weight values: in water and in air. It is not common to quote the C of G in water, but in fact this is the one which is relevant for fishing operation. The position of the C of G for a board built from only one material does not change with its situation (i.e., in or out of water) but when boards are made of a mixture of materials the C of G will change.

The C of G of an existing flat otter board without appendages can be found empirically in the following way (Figure 38):

(*a*) Suspend the board from corner "A" and, using a plumbline from the point of suspension, chalk on the vertical line.

(*b*) Suspend the board from corner "B" and again use a plumbline to mark on the vertical line. The C of G is the point where these two lines intersect.

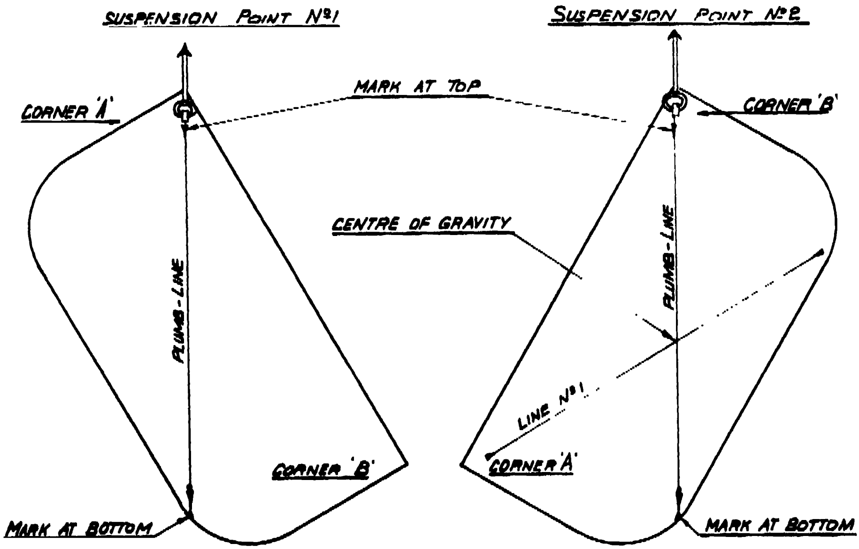


FIGURE 38. — Schematic drawing showing the method of determining the centre of gravity of a rectangular flat otter board.

A further check can be made by suspending the board from yet another point and again drawing in the vertical line from the point of suspension; this line should pass through the intersection of lines A and B. During this exercise the board can also be weighed.

For flat otter boards with appendages like warp brackets in operational position and also for cambered or Vee type boards, the C of G will not lie within the thickness of the actual board but more or less outside. In these cases the plumb line position cannot be marked directly on the board and some means must be employed to fix the plumbline positions and the point of intersection. Nails, wires, pieces of twine, etc. may be used.

The procedure is naturally simpler in air than in water where a diver is required and care must be taken to ensure absence of currents. Materials like wood, which absorb water, must be completely soaked before taking the measurements.

It must further be pointed out that the C of G in water as determined by plumblines is actually the point of application of the resultant force of the vertical downward force of weight of the board and of the vertical upward force caused by the water displacement, that is, the intermediate of the centre of gravity in air and the centre of buoyancy, the latter being located in the centre of gravity of the total volume of water displaced by the otter board.

In a well-designed otter board, the C of G in water is placed below the centre of buoyancy so that an uprighting moment will result from the combination of the two forces — weight in water and lift from water displaced. This uprighting moment increases the working stability of the board in trawling operation. In some trawl fisheries using light otter boards, the buoyancy is increased and the centre of buoyancy shifted upward by attaching a number of floats to the upper edge of the board. Floats are included for the same reason in the upper part of the high aspect ratio full-profile Japanese otter board mentioned above. In most otter boards (the only exception among the sheering devices described in this manual is the diverting depressor, which is self-righting on the bottom), the uprighting moment is, however, not sufficient to secure the board in a vertical position on the seabed. Without any towing force acting, it will fall either on the inner side (i.e., on its brackets) or on its outer side (the board "falls flat"). In the last instance it is rather difficult to upright the board against the sheering force, which then acts downward and some special manoeuvres are necessary — for example, a sharp turn of the vessel course toward the side opposite to that of the fallen board or hauling in warps under tow until the board comes free of the bottom.

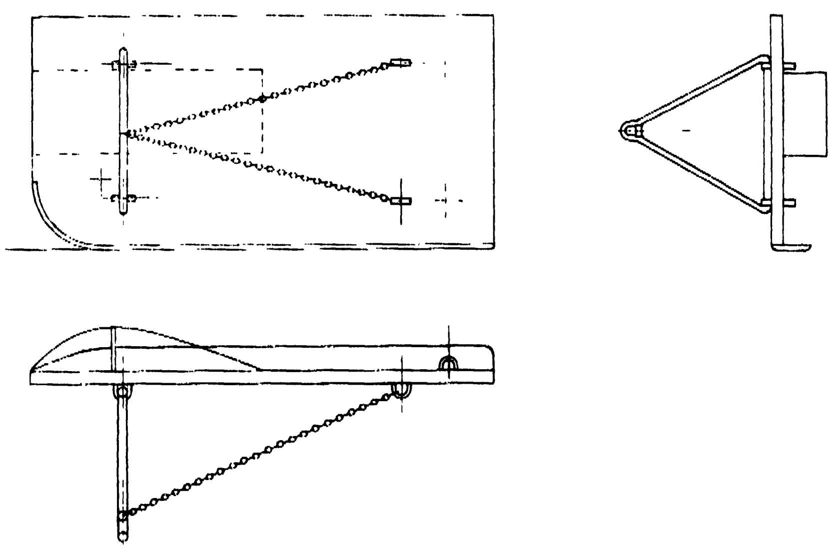


FIGURE 39. — Special ski on the rear side of a rectangular flat otter board to facilitate uprighting.

In order to avoid, or at least reduce the need for such manoeuvres, some otter board designs include special means to facilitate their uprighting, such as the additional buoyancy at the upper edge just mentioned, or a kind of ski placed on the outer side (Figure 39).

CHAPTER 5

SUMMARY

As presented in Table 4, the summary of the main hydrodynamic, operational, technical and economic aspects of the otter board types discussed in this manual is meant to facilitate selection for specific fishing conditions. Apart from serving developing fisheries, this may also induce some reconsideration of present practices regarding opportunities for improving trawling efficiency.

Following are the considerations that could enter into the choice of otter board type:

1. Trawling conditions — for smooth and even grounds all types are basically suitable. Rough or very rough and uneven grounds restrict the selection to certain types. For midwater trawling even fewer types are suitable. Dual-purpose trawling needs particularly careful consideration.

2. Hydrodynamic efficiency — must be related to operational characteristics and the relative importance of these two aspects will largely depend on prevailing fishing conditions, type and towing power of the trawlers available and the professional skill of skippers and crews. Naturally, highest possible hydrodynamic performance should be aimed at.

3. Construction and maintenance — in commercial operations, local facilities must be adequate at least for maintenance and repair, but preferably also for construction. For testing the feasibility of a specific type for local conditions, the purchase of proven prototypes is advisable irrespective of present lack of facilities which could eventually be established later.

4. Costs — in certain cases high costs may interfere with the rational choice of optimum operational and hydrodynamic characteristics. In this respect the long-range aspects should be carefully considered (e.g., realistic expectance of better catches, life time of the boats, etc.). Also, the possible reduction of cost by local construction should be taken into account.

5. Existing experience — obviously the risk of failure is greatly reduced by relying on long-term experience demonstrated by extensive use elsewhere and by selecting a well-proven design. But this attitude can hinder progress. The fact that a practical design like the rectangular flat otter board has been used extensively since the beginning of otter trawling does not necessarily mean that, in the light of technical progress, it is still the best solution available.

The final selection will undoubtedly be a compromise, but it will pay in the long run if adequate care is taken to ensure that it is the best possible compromise.

It must be stressed that the data for hydrodynamic characteristics in Table 4 refer to the commonly used angles of attack which are also given. As can be seen from the relevant curves for coefficients of sheer (C_L) and drag (C_D) and the respective hydrodynamic efficiency expressed by the sheer-to-drag ratio (C_L/C_D) in Figures 9 and 10, these angles of attack are for most otter boards, and in some considerably, larger than optimum. As an example, in Table 5 relevant data are given for maximum spreading force. This commercial practice, which is based on long-term operational habits, results in lower sheer and higher drag than could be obtained. A noteworthy exception is the Süberkrüb type otter board for midwater trawling which, unlike the conventional rectangular flat otter boards, was designed according to engineering principles.

TABLE 5. — EFFICIENCY OF OTTER BOARDS ON THE BOTTOM RELATED TO MAXIMUM SPREADING FORCE (C_L MAX) ACCORDING TO FIGURES 9 AND 10

Otter board type	C_L max	C_D	C_L/C_D	Respective angle of attack
Rectangular flat	0.89	0.55	1.62	29°
Rectangular cambered low aspect ratio	1.30	0.73	1.71	31°
Oval flat, slotted	0.94	0.52	1.81	29°
Oval cambered, slotted (polyvalent type)	1.03	0.58	1.78	29°

The prevailing practice of towing otter boards with a non-optimum angle of attack is a clear waste of towing power which has to be compensated by larger main engines. This is no problem for certain long-distance trawlers in which the determining factor of engine power is high speed so that the

towing requirements are adequately covered. But for most smaller trawlers, where towing power is the main limiting factor for the type and size of trawl gear and respective towing speed, it is well worth while to aim at optimum efficiency of the otter boards; this includes the appropriate rig for the best compromise angle of attack with regard to hydrodynamic and operational efficiency.

TABLE 4. — SUMMARY OF MAI[illegible]

Otter board type	Common angle of attack	Corresponding hydrodynamic characteristics: Coefficients of sheer C_L	drag C_D	Lift/drag ratio C_L/C_D	Overall efficiency	Fishing suitabili[illegible]: Manoeuvrability	On the seabed [1]
1. Conventional rectangular flat	40°	0.82	0.72	1.14	Average to poor	Good	A,B good C poor
2. Rectangular flat, wide-keeled	40°	0.82	0.72	1.14	Average to poor	Good	A good B poor C unsuitable
3. Rectangular cambered	35°	1.26	0.81	1.55	Good	Average (difficult to right if fallen over)	A,B good C poor
4. Ovat flat, slotted	35°	0.86	0.63	1.36	Average	Average to good	A,B,C good
5. Oval cambered, slotted (polyvalent type)	35°	0.93	0.74	1.25	Average to good	Average to good	A,B,C good
6. Rectangular Vee type	40°	0.80	0.65	1.23	Average to poor	Good	A,B,C good
7. Rectangular flat special design (diverting depressor)	40°	0.82	0.72	1.14	Average to poor	Very good	A,B good C average
8. Rectangular cambered, high aspect ratio, for midwater trawling (Süberkrüb type)	15°	1.52	0.25	6.08	Very good	Midwater good; bottom average to poor	A,B good C unsuitabl[illegible]
9. Rectangular cambered, high aspect ratio, for bottom trawling (Japanese type)	25°	1.30	0.50	2.60	Very good	Average (risk to fall flat)	A,B good C unsuitabl[illegible]

[1] For quality of seabed:
A = good ground, even, absence of boulders, etc.
B = medium ground, stones, no sudden major depth changes
C = bad ground, large boulders, uneven, sudden and major depth variations.

midwater	Construction considerations: Extent of special skills and tools needed	Costs: Purchase	Costs: Maintenance	Experience record
Poor	Average	Average	Average	Well proven; extensively used for demersal fishing
Poor	Less than average	Low	Low	Well proven; extensively used for small vessels and for shrimp trawling
Poor	Above average (bending facilities needed)	High	Average	Very limited commercial use to date
Poor to average	Above average	High	Average	Well proven; widely used, particularly by large trawlers
Average to good	Above average (bending facilities needed)	High	Average	Recent development; use increasing
Poor	Average	Average	Low	Well proven; extensive use, particularly for trawlers up to 600 hp
Average	High	Very high	Low	Recent development; limited commercial use so far
'ery good	Above average (bending facilities needed)	Average to high	Low	Well proven; extensively used for midwater trawling by trawlers of all sizes
Good	Above average (bending facilities needed)	Average to high	Average	Extensive use but limited so far to Japanese trawlers

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